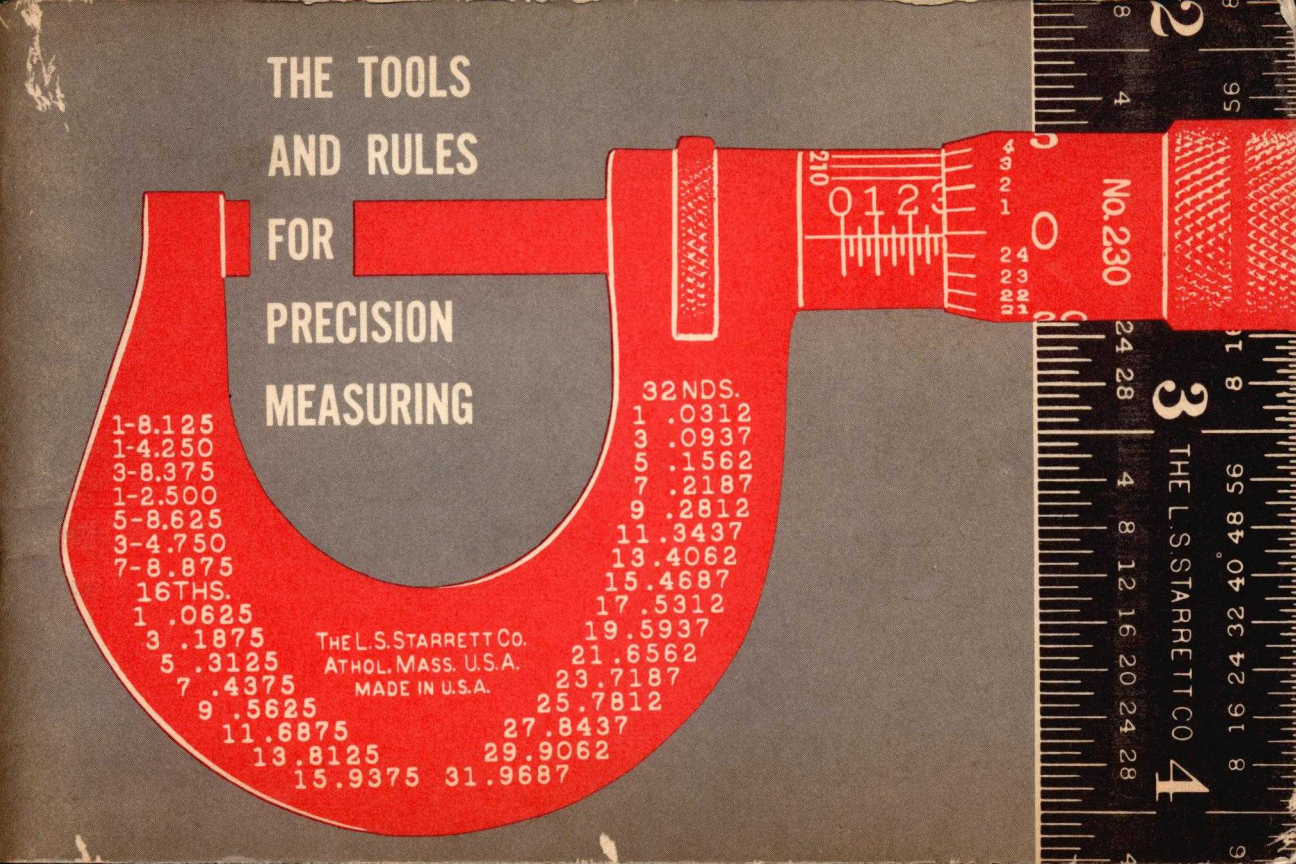
THE TOOLS
AND RULES
FOR
PRECISION
MEASURING
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THE L.S.STARRETT CO.
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THE L.S.STARRETT CO

*"Man is a tool-using animal. Weak in himself and of small stature, he stands on a basis of some half square foot, has to straddle out his legs lest the very winds supplant him. Nevertheless, he can use tools, can devise tools; with these the granite mountain melts into light dust before him; seas are his smooth highway, winds and fire his unwearying steeds. Nowhere do you find him without tools. Without tools he is nothing, with tools he is all."*

*Thomas Carlyle (1795-1881)*

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## THE TOOLS AND RULES FOR PRECISION MEASURING

In this modern age of space, mass production demands precision measuring. All parts in any product must be completely interchangeable. This necessary uniformity is assured and controlled through every operation by accurate measuring equipment. From blueprint to finished assembly, precision measuring is the guide to perfection. For precision measuring, the skilled mechanic must have accurate tools, produced from quality materials, carefully manufactured and rigidly inspected, to insure lasting dependability. Accurate measuring tools, in the hands of skilled mechanics, result in work approaching perfection.

### EARLIEST MEASURING TOOLS

Precision has not always been associated with measurement. At the dawn of civilization, man began to use parts of the body to estimate dimensions and about 6000 B. C., from such measurements, there finally evolved the inch, hand, span, foot, cubit, yard and fathom, the first standards of measurement.

The tools of the past did not demand great accuracy. Most products were custom made by hand and a fraction of an inch one way or the other made little difference to satisfactory operation. It was Eli Whitney who first conceived the basic idea of mass production through interchangeable parts and that

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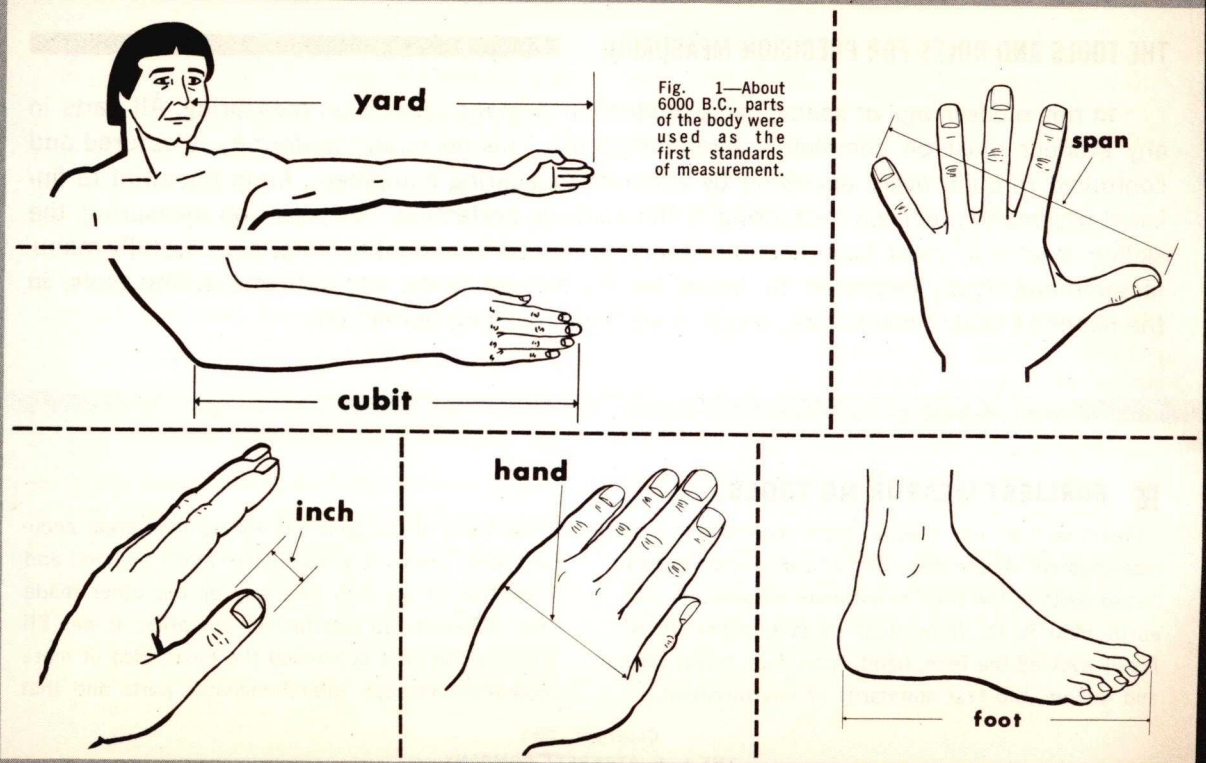



Fig. 1—About 6000 B.C., parts of the body were used as the first standards of measurement.

only through improved methods of measurement and mechanically powered machines would mass production become possible. In 1800 he successfully applied his theories to the manufacture of muskets for the U. S. Government and is remembered today as the father of mass production through duplicate parts.

Due to Eli Whitney's concept, the 19th century saw a tremendous growth in mass production of all types of goods. Although this development was possible because of the greater use of mechanically powered machine tools instead of hand tools, and better measuring devices, machines and measuring tools approaching the accuracy of modern standards were not developed until after the Civil War.

Even before this time, in 1848 in China, Maine, a boy of twelve developed an interest in tools which in later years grew into a great company and earned the title, "World's Greatest Toolmakers." This small boy's name was Laroy Starrett. Love of tools and a flair for invention sparked a long career that carried on Eli Whitney's earlier concept of mass production through precision tools.

Laroy Starrett had "invention on the brain" and as a young man on the farm he spent much of his time in winter and on stormy days working with tools and developing ideas. His first invention was a meat chopping machine which he began to manufacture and sell throughout the country. In 1868 he moved to Athol, Mass., and resumed operations in a small shop.

## MODERN MEASURING TOOLS

Laroy Starrett's main interest, however, was in the development and improvement of precision measuring tools, and the Combination Square was the first in a long line of such tools. From 1877 throughout the rest of his life, he devoted all of his energy and Yankee ingenuity to creating new and improved tools. Among these were spring tempered and flexible steel rules, steel tapes, calipers and dividers, the micro-

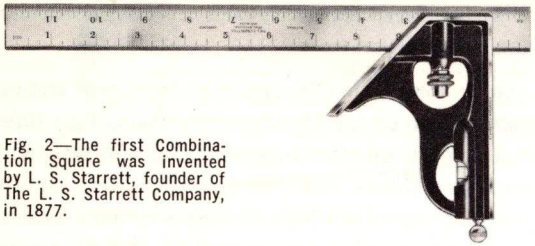


Fig. 2—The first Combination Square was invented by L. S. Starrett, founder of The L. S. Starrett Company, in 1877.

meter caliper, Vernier calipers, height gages and many other tools, including metal cutting saw blades. This was Laroy Starrett's contribution to the present modern science of precision measuring and to the growth of industry as we know it today.

Nearly all measurements common in shop practice involve measurements of length. Linear measurements are so numerous and of such importance that a multitude of measuring tools are available for the purpose of obtaining them.

**THE YARD AND THE METER.** Two units of linear measurement are now common in the United States. One, the British yard, as defined by the Weights and Measures act of 1878 is most familiar in its subdivisions of feet, inches and fractions of an inch. Once as loosely defined as the distance from the thumb-tip to the end of the nose of English King Henry I, it is now more precisely defined by the British as the distance between lines inscribed on two gold plugs in a bronze bar when taken at a specified room temperature. We, too, have a prototype of the yard which is kept in the Bureau of Standards in Washington but prefer to base our definition of the yard more precisely in terms of light waves, or use the new International Inch.

The meter, which is the basis of the metric system accepted as the standard system of measurement in many countries, is subdivided into centimeters, millimeters, and fractions of a millimeter. Most shops handling instrument and scientific work as well as producing parts for export are equipped with measuring tools calibrated by the metric system.

## NEW STANDARDS OF PRECISION

**THE INTERNATIONAL INCH.** The modern International Inch is based on the wavelength of monochromatic light from Krypton 86 gas. The length of a single wave is 0.0000238 inches, giving us an absolute standard which never changes. Combine 42,016.807 of these light waves and you have the International Inch. Measurement of these microscopically small light waves is done by a process called Interferometry using an instrument called the Interferometer. Another method is called Spectroscopy which uses units of length called angstrom units, each measuring less than 4 billionths of an inch.

Although a light wave cannot be handled like a micrometer or a caliper, it can be used to establish the length of physical standards with accuracy to a few millionths of an inch. These standards are called gage blocks and are used throughout industry as a practical shop tool. They are made in many sizes and can be combined to give practically any required dimension.

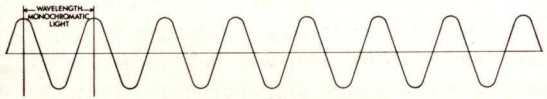



Fig. 3.—The modern International Inch is based on the wavelength of monochromatic light.

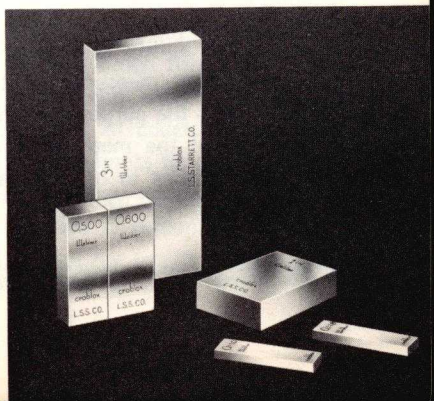



Fig. 4—Gage Blocks are used throughout industry as standards and have accuracy to a few millionths of an inch.

## KNOW YOUR LIMITS

While on the subject of accuracy, a word of advice may not be amiss. It is quite possible to be too accurate in production work. Striving for accuracy beyond prescribed limits can be just as inefficient and wasteful of time and effort as gross inaccuracy. Not even pride of workmanship can justify one craftsman slowly and painstakingly producing parts to an accuracy of one ten-thousandth while his bench mate turns out matching components that merely meet the specified tolerance of plus or minus several thousandths. What is desired, and that to the highest degree, is the ability to produce work rapidly and consistently that measures up to the established standards. It is the purpose of this booklet to review the means and the methods of achieving uniform accuracy according to the standards commonly accepted in industry today.

## SIGHT AND TOUCH

Recent developments in the field of precision measuring have made the modern tool more accurate and far easier to read. These include easy reading Satin-Chrome Finish and widely spaced 50-division Verniers, new tools of all types featuring dial indicators, electronics, optics — to name a few. However, to develop habits of consistent accuracy in measurement, it is well to remember that we still are dependent upon either of two senses in making nearly all measurements — the sense of sight or the sense of touch.

The sense of touch becomes important when using contact measuring tools. A skilled mechanic with a highly developed sense of "feel" can readily detect a difference in contact made by changes in dimension as small as 0.00025". While the acuteness of the sense of touch varies with individuals it can be developed with practice and proper handling of tools. In the human hand, the sense of touch is most prom-

Fig. 5—When contact measuring tools are held lightly by the fingers, it is possible to "feel" extremely slight differences in dimension.

Fig. 6—Although "feel" is important in adjusting a Micrometer to measure the work, actual size is read directly from graduations on sleeve and thimble.

inent in the fingertips; therefore, a contact measuring tool should be properly balanced in the hand and held lightly and delicately in such a way as to bring the fingers into play in handling or moving the tool. If the tool is clumsy or is harshly grasped, the sense of touch or "feel" is greatly reduced.

**ESTIMATION.** Sight and touch are frequently combined by the skilled worker to estimate measurements finer than the graduated limits of a tool. For example, on the average micrometer graduated to read to thousandths of an inch, the space between the smallest graduations on the thimble is approximately $\frac{1}{16}$ inch. Variations in size much smaller than the thousandth of an inch which this space represents can readily be felt and judged by eye with reasonable accuracy. It is, of course, always best practice to work within the limits for which a measuring tool is designed, but when circumstances make it necessary, it is possible to extend the limits by estimating sub-divisions of the smallest graduations in simple fractions such as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc.

**CARE OF TOOLS.** It goes without saying that precision measuring tools should be handled with the greatest of care. Good tools will stand a lifetime of use without breakage, but the accuracy of even the finest tool can be quickly impaired by careless or abusive treatment. In working with measuring tools, be careful to avoid accidental scratches or nicks that will obscure graduations or distort contact surfaces. Rust is the enemy of all finely finished surfaces. Tools should be wiped clean of finger prints after using and kept in separate boxes or cases. A light dressing of oil applied with a soft, lint-free cloth will protect tools in storage.

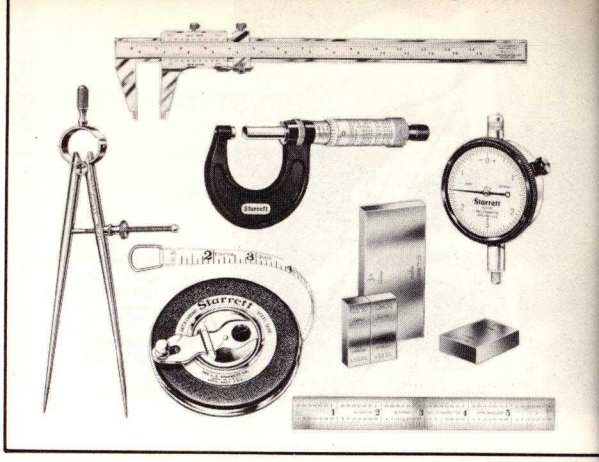



Fig. 7.—A wide variety of tools are available for linear measurements as illustrated here.

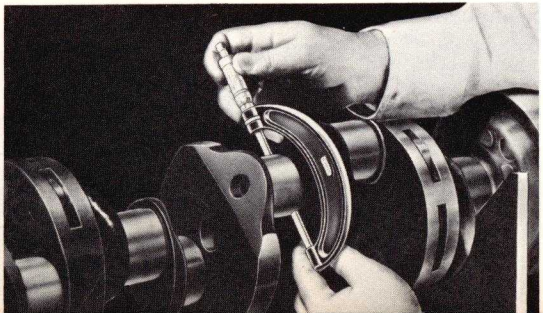
## LINEAR MEASUREMENTS

**LINEAR MEASUREMENTS** on flat surfaces are perhaps the most common measurements made in general practice. The tool used varies with the size of the dimension, the nature of the work and the degree of accuracy required. It may range from a steel tape, rule, divider or trammel to a micrometer, Vernier caliper, dial indicator or optical gage. The measurement may be made direct as with a micrometer or Vernier caliper in which the dimension is read directly from a graduated scale with the tool in contact with the work or it may be made indirectly by comparison with a separate standard or gage blocks using a surface gage, height gage or test indicators, depending on accuracy required, to trans-

fer the measurement. Many related tools such as straight edges, steel squares and protractors are used in conjunction with linear measuring tools to determine flatness, straightness, squareness and angularity.

**FOR ROUND WORK,** measurements are usually made by contact, using tools with contact points or surfaces such as spring calipers, micrometers, Vernier calipers, dial gages, etc. Contact measurements are made in two ways: (a) by pre-setting the tool (a dial snap gage for example) to the required dimension, using a micrometer, gage blocks, or other tool as a standard, and then comparing the set dimension with the actual size of the work and (b) the reverse of this method, setting the contact points to the surfaces of the work and directly reading the size from a micrometer, Vernier caliper or dial gage. The first method is often used where repeated tests must be made such as in machining a piece to a given size or when checking the same dimension on a number of identical parts. The second method is used for determining the actual size of the piece.

Fig. 8—Measuring round work, a crankshaft journal, with an Outside Micrometer.



## STEEL RULES AND RELATED TOOLS

**THE RULE** is a basic measuring tool from which many other tools have been developed. Rules are so essential and so frequently used on a variety of work that they are offered in a truly amazing selection to suit the needs of the precision worker. They range in size from as small as one-quarter inch in length for measuring in grooves, recesses and keyways to as much as twelve feet in length for large work. Satin-Chrome Finish, a relatively recent develop-

ment, gives today's rules longer life and far greater ease of reading. Steel rules are graduated in the English or Metric system and sometimes scales for both systems are provided on a single rule. They can be graduated on each edge of both sides and even on the ends. English system graduations are commonly as fine as one-hundredth inch in decimals or one sixty-fourth inch in fractions. Metric graduations are usually as fine as one-half millimeter. Starrett rules are graduated to agree with accurate standards calibrated by the United States Government. These standards are sent to the Bureau of Standards at Washington at frequent intervals to check for accuracy so that even minute errors due to wear can be detected and provided for.

**VARIATIONS OF THE STEEL RULE.** Close working mechanics lean to the 6-inch rule as the most convenient length to carry about on the person. For such purposes, a spring tempered rule is desirable since it is both thin and flexible yet has ample stiffness to provide a straight measuring edge. Small rules are available with a tapered end for measuring

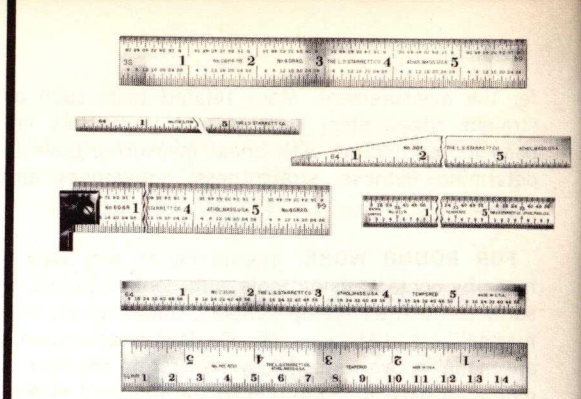
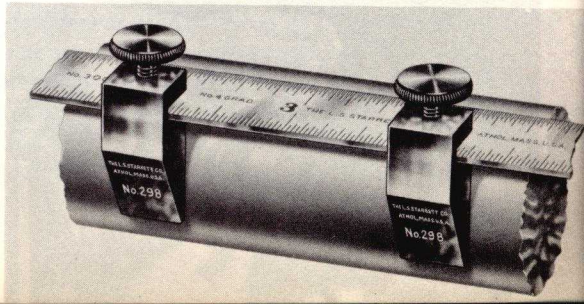


Fig. 9—The Steel Rule is one of the basic measuring tools. Various types in English and Metric are shown.

Fig. 10—Any steel rule can be converted into a Key Seat Rule with these clamps.



in small holes, narrow slots, from shoulders, etc.

The Hook feature which is available on many rules is a decided convenience. Not only does it provide an accurate stop at the end of the rule for setting calipers, dividers, etc., but it can be used for taking measurements where it is not possible to be sure that the end of a plain rule is even with the edge of the work.

**KEY-SEAT-RULES** are necessary for laying off measurements or drawing lines parallel to the axis of cylindrical work such as measuring lengths for splining keyways on shafting. By means of key-seat clamps any steel rule can be quickly converted into a useful key-seat rule as shown in Fig. 10.

One Starrett folding steel rule is graduated in the normal way and also in circumference inches so that both the diameter and the circumference of cylindrical work can be read directly from the same rule.

**SHRINK RULES** are used for laying out casting patterns and core boxes. Because the contraction of various metals varies greatly, as for example: cast iron, $\frac{1}{8}$ inch to each foot; brass, $\frac{3}{16}$ inch to each foot; and tin alloys, $\frac{1}{12}$ inch to the foot, shrink rules are made oversize to allow for this contraction and graduated to distribute the extra length uniformly throughout the rule. Double shrink rules are used when a working pattern is cast from a master pattern as in production moulding and two shrinks must be provided for.

**THE STEEL TAPE** provides a logical extension of a graduated measuring tool beyond the practical

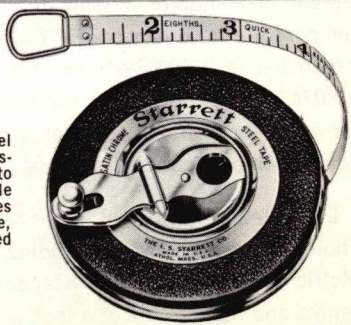



Fig. 11 — Steel Tapes permit measuring lengths up to 100 feet. Available with tape lines in Satin Chrome, White, and Etched Steel finish.

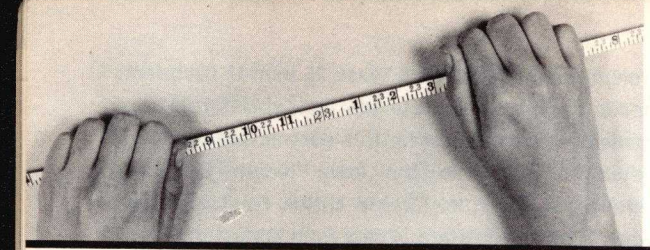


Fig. 12 — Quick reading figures on a Steel Tape eliminate confusion and errors. Foot figures in red and red foot figures before every inch mark. Red flag every 16 inches shows stud centers.

limits of a steel rule. Although available in lengths up to 100 feet, they are still accurate. Every Starrett tape is made to bench standards certified for accuracy by the United States Government National Bureau of Standards, Washington, D. C..Standard for temperature is 68 degrees Fahrenheit; co-efficient of expansion is 0.00000645" per inch per degree F. or 0.00774 inch per degree per 100 feet; standard tension for steel tapes up to 100 feet long supported horizontally throughout is 10 pounds.

Like steel rules, steel tapes are available in a choice of graduations including English, Metric, Metric and English, and in special graduations — tenths and hundredths of a foot, and links and poles for surveyors. Satin-Chrome or White tape lines with quick-reading graduations and foot figures and 16-inch stud marks in red make reading easy and give long tape life.

**SLIDE CALIPERS** are a refinement of the steel rule which make it possible to insure greater accuracy in aligning the graduated scale with the edges or points to be measured. With these tools, a head or

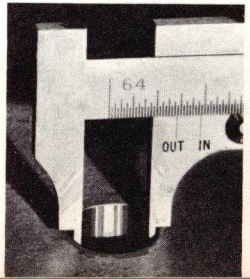
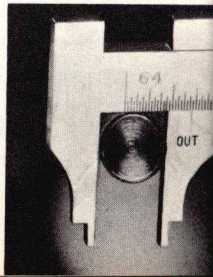



Fig. 13 — Pocket Slide Calipers measure both inside and outside dimensions.



pair of jaws is added to the rule, one jaw being fixed at the end and the other movable along the scale. Provision is made for clamping the movable jaw to lock the setting and often a fine pitch screw is provided for fine adjustment of the slide. The slide is graduated to read inside or outside measurements.

**DEPTH GAGES** are an adaptation of the rule or scale for measuring the depth of holes, recesses, etc. They are provided with a sliding stock or base set at right angles to the scale and with means for clamping the slide to lock the reading.

**A COMBINATION SQUARE** represents a rule developed by means of attachments to the ultimate in utility. It consists of a graduated, hardened steel blade with a sliding try square head that also combines a mitre and level. This arrangement serves the multiple uses of a rule, square, mitre, depth gage, height gage and level. In addition, an auxiliary centering head can be substituted for the square head for finding the centers of shafting and cylin-

Fig. 14—Checking the depth of a blind hole with a Depth Gage.

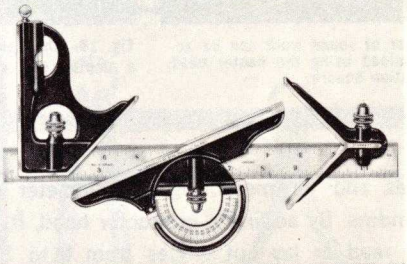


Fig. 15 — The Combination Set with its rule, square head, center head, and protractor has many useful applications in measuring.

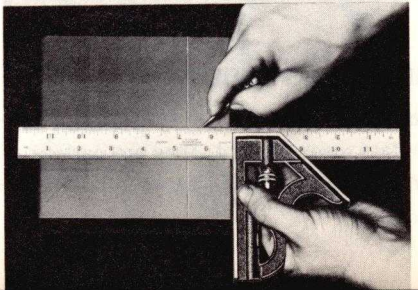


Fig. 16 — Scribing right angles and parallel lines with Combination Square.

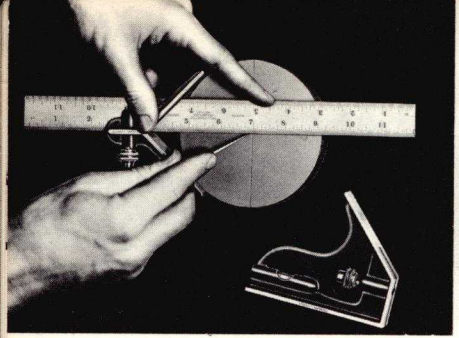


Fig. 17.—Center of round work can be accurately determined using the center head of the Combination Square.

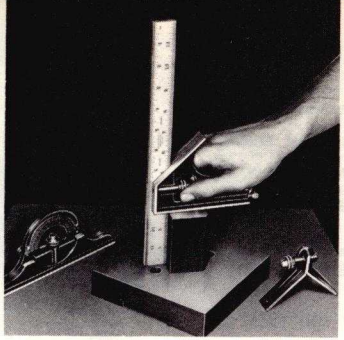


Fig. 18—The Combination Square used as a depth gage, a very handy application.

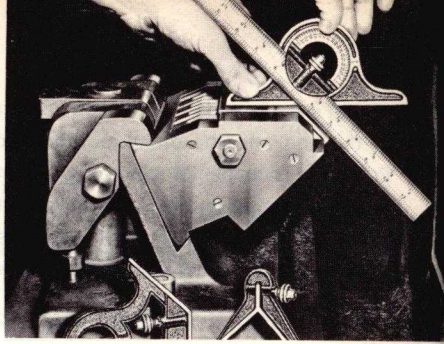


Fig. 19—The protractor head on a Combination Set accurately and quickly checks angles.

drical pieces and for measuring the diameter or bore of cylinders. By adding a protractor head, it is possible to read or lay out angles from 0 to 180 degrees.

## CALIPERS AND DIVIDERS

As previously mentioned, bow calipers are often used for contact measurement. They are particularly useful for measuring distances between or over surfaces or for comparing dimensions or sizes with standards such as graduated rules. Because they are used for checking work in a lathe, a word of caution may be in order. Calipers should never be used while the work is turning. At best, the readings are inaccurate and misleading because the friction of the moving surface is sufficient to spring the legs or to draw the contact point away from the true diameter. There is always the danger of having the

tool torn out of the hand with possible injury to the user.

**CALIPERS** with the legs shaped either for inside or outside measurements are made in "spring-bow" style with an adjusting nut and screw working against the tension of a spring; in "firm joint" style in which the tension of a nut and stud provides sufficient friction to hold the legs in any set position; and in "lock joint" style with a knurled nut which may be loosened for free movement of the legs and tightened to lock the setting. Transfer calipers are variations of lock joint calipers with a stud or stop on a freely moving leg fitting into a slot or against a stop on an auxiliary leaf. The free leg can be moved in or out to clear collars, flanges or other obstructions and then returned to the original setting against the stop to make the reading.

**DIVIDERS** are used for measuring dimensions between lines or points; for transferring lengths taken from a steel rule; and for scribing circles or arcs. The contacts are sharp, hardened points at the ends of straight legs and close measurements are made by visual comparison rather than by feel. Dividers are restricted in range by the opening span of the legs and become less effective for scribing and similar uses when the points are sharply inclined to

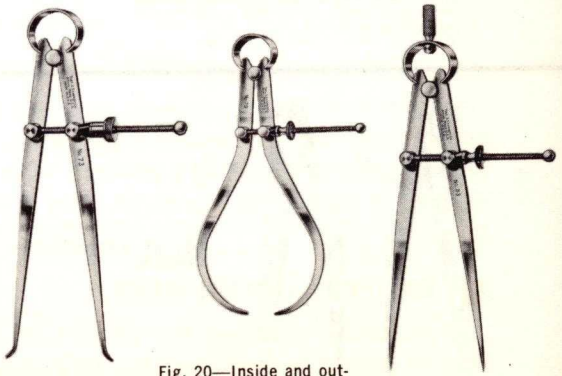


Fig. 20—Inside and outside Calipers and Dividers are typical "contact" measuring tools.

the surface worked upon. For transferring or scribing dimensions of considerable length, the mechanic resorts to a trammel on which the points are adjustable along a bar or beam and the legs are always perpendicular to the surface worked upon.

**HERMAPHRODITE CALIPERS** combine a straight divider leg and a curved caliper leg and are used for scribing parallel lines from an edge or for locating the center of cylindrical work.

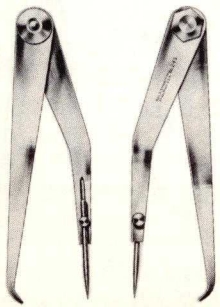


Fig. 21—Hermaphrodite Calipers.

## HOW TO TRANSFER MEASUREMENTS

**TRANSFERRING MEASUREMENTS** may be a delicate job or not, depending upon the degree of accuracy sought. One of the most common of all tools for transferring measurements is the bow caliper. These are made with the legs curved inward or outward for making outside or inside measurements. When the calipers are set to the work, care should be taken to bring the points into contact without excessive pressure that might cause the legs to spring and introduce an element of error. The measurement is then transferred to a steel rule. In this way, it is possible to transfer lengths with an error of less than 0.002". More accurate readings can be obtained when a micrometer or Vernier caliper is used to measure the distance between points of the spring caliper. It is here that the sense of "feel" becomes important in judging measurements precisely. Differences in size too small for the eye alone to detect can be readily felt as differences in the ease with which the tool slips over the work or between contacts of the standard. In setting calipers either to the work or to the standard, a firm but not hard contact is desirable. The feel of the slight

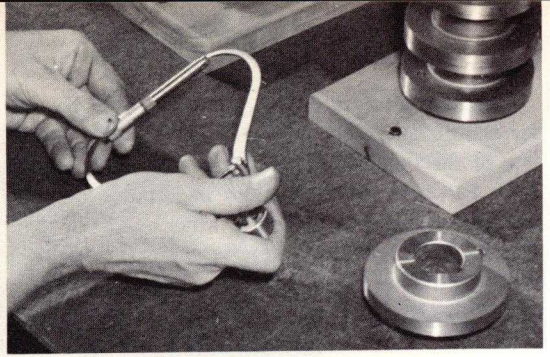


Fig. 22—Pre-setting Outside Calipers to an Inside Micrometer for a transfer measurement.

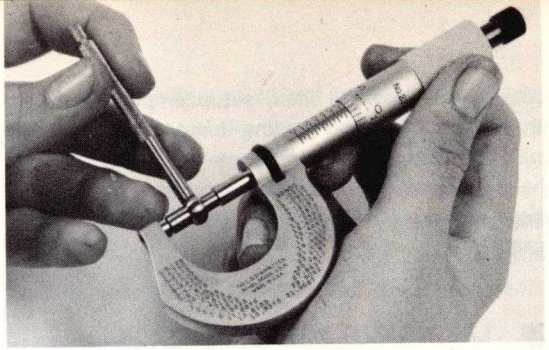


Fig. 23—After establishing hole size with a Telescoping Gage, actual size is determined by measuring over the contacts with an Outside Micrometer.

resistance to movement of the contact points can be retained in the memory long enough for precise comparison between work and standard.

While it is possible in this way to transfer by feel a length with as small an error as one-quarter of one thousandth inch, there are times when it is not practicable to do so without introducing possibilities of error. For that reason, mechanics prefer to use tools which can be read directly in thousandths or ten-thousandths of an inch, such as micrometers or Vernier calipers for more accurate contact work. Here again, the sense of feel is important and developing the habit of using the same pressure for every measurement when setting the contact points contributes greatly to uniform accuracy.

For ultimate accuracy in transferring measurements, a height transfer gage such as shown on

page 52 is used. An ideal setup employs an electronic amplifier and gaging head in conjunction with the height transfer gage for checking work height in millionths of an inch, the gage having been previously set to height from an optical height gage.

## LAYING OUT WITH ACCURACY

**LAYING OUT** is a shop term which includes the placing of lines, circles, centers, etc. upon the surface of any material to serve as a guide in shaping the finished piece. It is somewhat analogous to mechanical drawing but differs in one important respect. The lines on a mechanical drawing are used only for reference in visualizing dimensions and are not measured or transferred. For that reason, exact accuracy of spacing is not required. In laying out work, even a slight error in placing a line or center may result in a corresponding or greater error in the finished piece. For that reason, all lines should be exactly located and all scriber, divider and center points should be exact and sharp.

Fine and accurate laying out which paves the way for accurate working and finishing continues to be one of the best examples of the precision worker's skill. Far from diminishing in importance as mass production methods introduce wider use of jigs and fixtures for duplicate production of parts, its value grows as the need for greater accuracy in the making of the jigs, fixtures, tools and production machines increases.

**PREPARING THE SURFACE.** For rough surfaced work such as castings or for simple work where no great accuracy is required, rubbing chalk or a mixture of white lead and turpentine upon the surface of the work will serve as a coating to make scribed lines more visible. For fine, exact layouts, on smooth or finished surfaces, a special marking solution should be used. One in common use is a mixture of one ounce copper sulphate to four ounces water to which a little nitric acid may be added. This solution applied to clean iron or steel gives a dull coppered surface on which even the finest scribed lines are clearly visible.

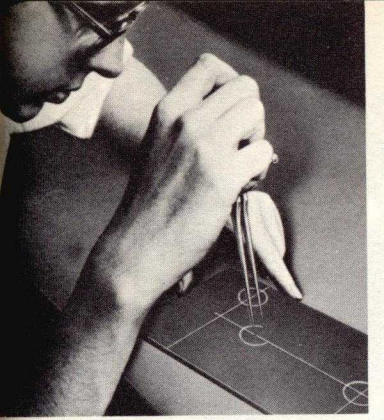
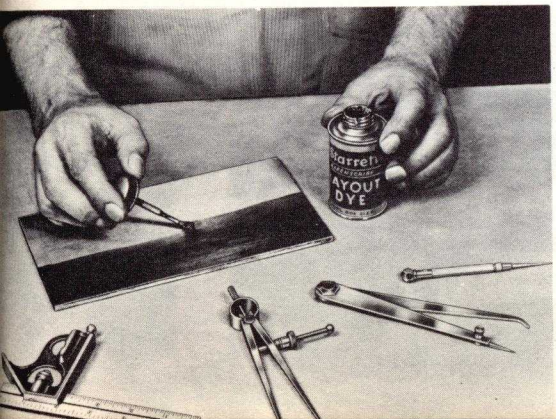


Fig. 24—For precise layout of three identical circles, this mechanic uses 6″ Spring Dividers.

Fig. 25—Layout dye being applied to a metal surface. Produces an opaque blue background ideal for layout.




For shops doing a volume of layout work, there are available commercially prepared products, such as Starrett Layout Dye, which may be applied to any metallic surface and which will take clean, sharp scribed lines without chipping or peeling. For best results, the surface should be free of grease, oil, cutting solution, etc., before the dye is applied.

**SCRIBING LINES.** An important feature of scribers, dividers, scratch gages, trammels, surface gages and similar marking tools is a nicely finished, well tempered point, free from burr or distortion. Points should be checked frequently and ground or honed as required. The straight edges of rules, squares and

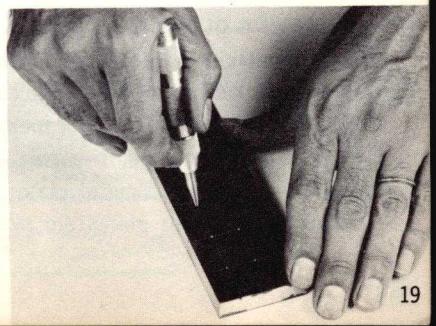


Fig. 26—Punching center holes on ground flat stock with Automatic Center Punch for a drilling operation. Holes were previously located by scribing intersecting lines.

protractors should also be inspected for dents and nicks and checked for trueness from time to time against a master square. Since the location of centers for drilling and the intersection of lines are marked with punched indentations, care in using a center punch is extremely important. Considerable practice is required to develop the knack of striking a single crisp tap or blow with a hammer to produce a deep or shallow dimple as desired. For fine work, an automatic center punch in which a built-in, adjustable spring provides the striking force is a great asset since both hands are available to steady the tool and it is not necessary to look away from the exact point of contact until the impression is made.

**LAYING OUT PLATE.** For accurate laying out and for precision inspection of finished work, some sort of plane surface of reliable accuracy is required as a base for the work and for measuring tools such as surface gages, height gages and steel squares. Special granite or metal plates known as leveling, surface or layout plates are available for this pur-

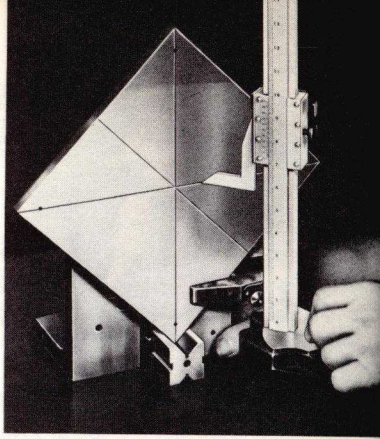
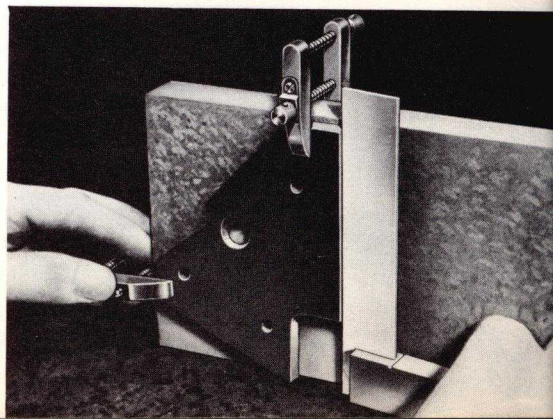


Fig. 27—Scribing lines on work with carbide scriber on Vernier Height Gage. Work is held by fixture on surface plate.

Fig. 28—To assure true vertical mounting, machinist checks workpiece against Hardened Steel Square before final clamping to angle plate.



pose. These are made in various sizes and are finished with a high degree of flatness and smoothness. Care should be exercised in placing and handling work and tools on the plate to avoid scratches and nicks and the plate should be protected with a suitable cover when not in use. All burrs, sharp edges and rough areas on the work should be removed before placing it on the plate.

Work of irregular shape or with protruding bosses can be supported and leveled by means of steel parallels placed in contact with any two points in a common plane. Finished work or castings with a better bearing surface on the side can be clamped to a knee or angle irons which are then placed upon or clamped to the surface or face plate. Toolmakers' clamps are used to hold the work securely.

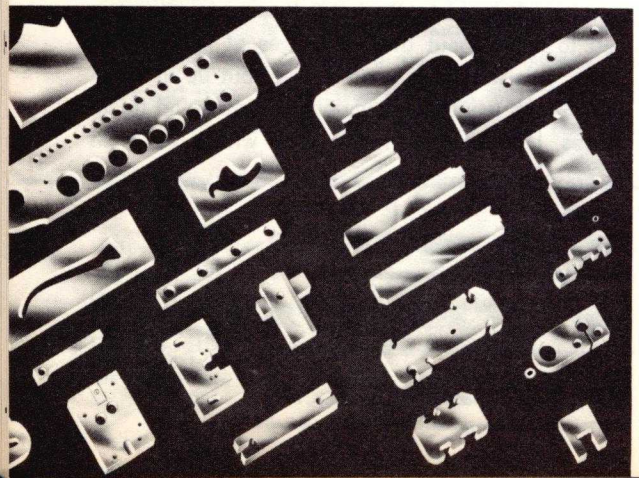
Where extreme accuracy is required, as in jig and fixture layout work, master precision squares in sizes from 1½" up to 36" and larger are essential and insure exact squareness between work and surface plate. Beam and blade of such squares are hardened, ground and lapped for precise parallelism and straightness. Die makers' squares are also available and by an angular adjustment feature can be used for checking the clearance in dies. Standard, bevel, narrow, graduated and offset blades adapt this square to a wide variety of work.

Since much layout work is concerned with the preparation of templates, gages, test and cutting tools, machine parts, jig and fixture parts, etc., it is well to know about the advantages of Ground Flat Stock. This is high grade tool steel put up in 18, 24 and 36 inch lengths in a variety of widths and thicknesses. It is accurately ground to within .001 inch

Fig. 29 — Templates, gages, tools, parts, etc. are easily and economically prepared from Precision Ground Flat Stock. Just lay it out and saw it out.

in thickness and annealed for easy machining. Many shops have no facilities for grinding to close limits and even those which do, prefer the time-saving advantage of keeping a stock of frequently needed widths and thicknesses on hand. Starrett Ground Flat Stock is available in three types: oil hardening, air hardening and low carbon.

Fig. 30—Some of the various parts which are readily made from Precision Ground Flat Stock.



## WORK LOCATION

Many types of tools are available for locating work in machining, layout, checking or inspection operations, either on surface plates, angle plates, or in various types of chucks and work-holding devices on machine tools. These include test indicators, toolmakers' buttons, center finders, edge finders and other devices. Work surfaces may be located easily, quickly and accurately with the edge finder as shown in fig. 31. Work with flat straight edges, shoulders, grooves, round work, studs, dowels, or center points and scribed lines—all can be accurately located with this handy tool.

## MEASURING LATHE WORK

Work done on the engine lathe is of such variety that a considerable list of measuring tools may be needed to cover all cases. Ordinarily, however, the principal measurements are concerned with centering the work in the lathe, measuring length and measuring diameters.

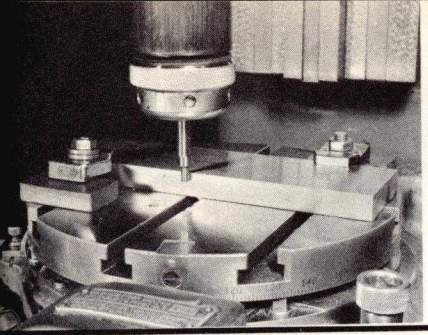


Fig. 31—Locating work from straight edge using Edge Finder mounted in chuck of machine tool.

**CENTERING THE WORK.** For efficient turning with a minimum of waste, and without excessive vibration, it is necessary to locate the center of work to be turned with considerable accuracy. When the work is turned from ordinary cylindrical bar stock, this can be done readily using the center head attachment and the blade of a combination square to scribe center lines on the end of the piece, shifting the tool about 90 degrees between lines to arrive at a common center. A hermaphrodite caliper may also be used with the legs opened to approximately half the diameter of the piece. Three or four arcs scribed from various points on the circumference will narrow down the location so that the true center can be estimated with considerable accuracy. The centers as determined by either method just described should be set with a center punch and then tested by spinning the piece in a lathe to check concentricity before drilling and countersinking the center holes. Where there is reason to suspect some distortion or variation in diameter of the work such as in forgings, it is good practice to use a height or surface gage and a surface plate to determine the centers. Lines scribed on the ends

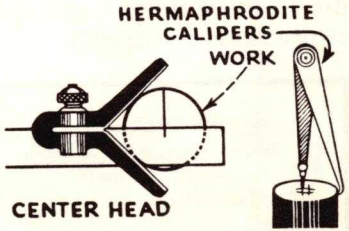



Fig. 32 — Two methods of locating centers: left, using center head of Combination Square; right, using Hermophrodite Calipers.

with reference to various points on the circumference will locate the center with provision for a fair average of surface errors and insure a reasonable balance while turning the forging to uniform diameter. Work so distorted as to teeter on the surface plate should be placed upon parallels or straight edges.

Center holes are countersunk to match the 60° included angle of lathe centers. It is good practice to check the angle of the live and dead center points from time to time to make sure that they have not become worn or distorted. This is done with a center gage, a little tool that is also useful in grinding and setting thread cutting tools.

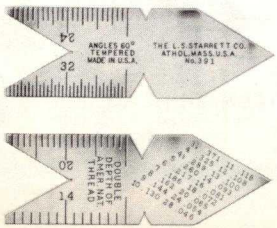



Fig. 33—Center Gages are used for checking lathe centers and for grinding and setting screw cutting tools.

**MEASUREMENTS OF LENGTH AND DIAMETER** are performed with steel rules, calipers and dividers, micrometers, Vernier calipers, dial indicator gages, etc., according to the nature of the work and the degree of exactness required. In addition to these, the lathe operator finds considerable use for a surface gage, test indicators, telescoping gages, and inside micrometers. The surface gage is useful for scribing lines around cylindrical work or for scribing concentric circles on the face of work held in a chuck. Test indicators vary from a simple needle and sector arm arrangement to highly accurate and sensitive dial test indicators. These are especially valuable for truing up work in a lathe chuck since they can be used for checking internal and external concentricity as well as surface alignment.

**TELESCOPING GAGES** are sometimes preferred to ordinary leg calipers for measuring internal diameters. The head of a telescoping gage expands across the hole and may be locked and calipered with a micrometer to determine the exact size or the gage

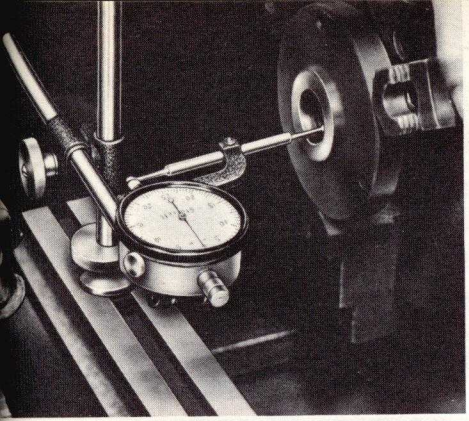


Fig. 34 — Lathe operator centers work in chuck using Dial Test Indicator with hole attachment. Heavy base resting on parallel, leaves operator's hands free for making adjustments.

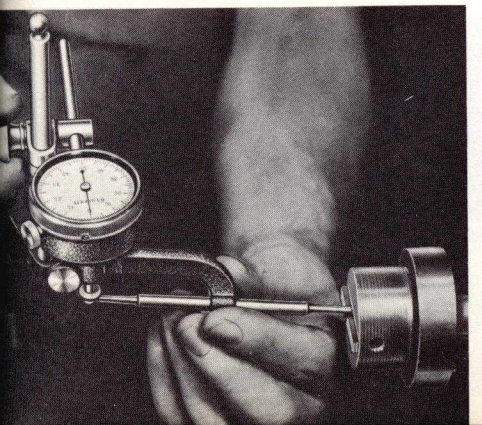


Fig. 36—Checking hole in workpiece before reboring, using heavy duty Dial Test Indicator with hole attachment. Tool post holder holds indicator securely in position.

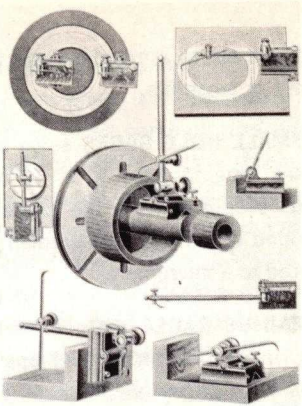


Fig. 35 — A Starrett Surface Gage and some of its uses.

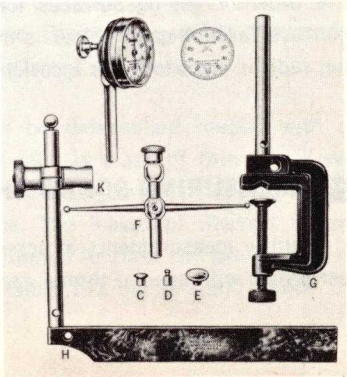



Fig. 37—Universal Dial Test Indicator with attachments.

may be set to a standard and used to make shrink, close or loose fits.

**SMALL HOLE GAGES** serve the same purpose for holes ranging from ⅛ to ½ inch. They are made with a split ball at the contact end which is expanded to get the measurement which is then transferred to a micrometer.

**RADIUS GAGES** are also very useful for machining, inspection and layout operations. These stainless steel gages provide radii from 1/64 to ½ inch. A gage is provided for each radius and each gage has five different gaging surfaces for both convex and concave radii. A gage holder is available for checking radii in hard-to-reach locations.

## MEASURING SCREW THREADS

Quantity measurements of screw threads are best performed with special thread gages or comparators,

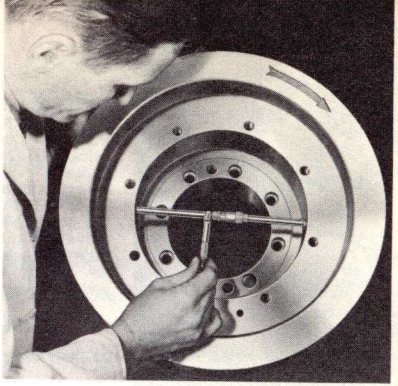


Fig. 38—Checking inside diameter of a deep hole with Inside Micrometer. Convenient handle is attached to center of the micrometer.

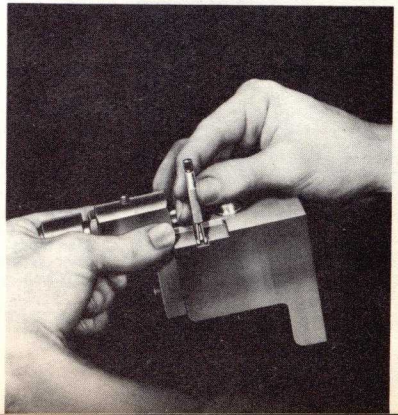


Fig. 39 — Small Hole Gages have ball contacts with flat ends permitting shallow slots and recesses to be measured.

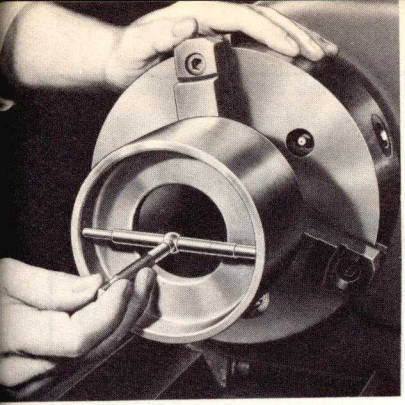


Fig. 40 — Accurate size measurements are insured with Telescoping Gage. Handle is automatically self-centering.

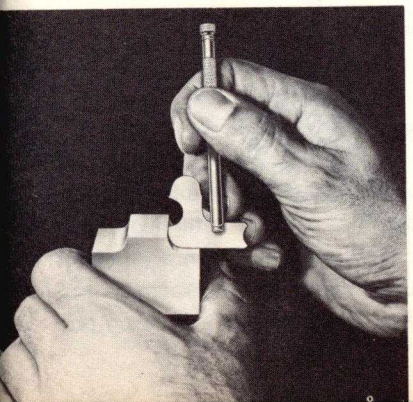


Fig. 41—Radius Gage in holder provides fast check of 1/4" radii milled on this workpiece.

but there are frequent occasions when such equipment is not available or when it is necessary to determine the number of teeth per inch, the pitch or the pitch diameter of a few bolts, nuts or threaded holes or studs. Where a count of threads per inch is desired, an ordinary steel rule may be used. Count the number of threads between inch graduations with the end of the rule exactly aligned with the root of one thread. Often the result will be less than a whole number or a whole number of threads plus a fraction of a thread. To arrive at the exact fraction, count the number of threads between the end of the rule and the first inch graduation that coincides exactly with a thread. Divide the number of threads by the number of inches.

Screw pitch can be determined readily with a screw pitch gage which is a set of thin leaves on the edge of which are teeth corresponding to standard thread sections. The leaves of Starrett Screw Pitch Gages are stamped to show the pitch number of the thread. Because the outside and inside or

major and minor diameters of threaded pieces may vary depending upon the sharpness or fullness of the thread, measurements are usually made at the pitch line to find the pitch diameter. The pitch diameter is equivalent to the theoretical full diameter less the depth of one thread. Screw thread micrometers with a pointed spindle and V-shaped anvil are used to measure pitch diameters. The point of the spindle and the V-shaped anvil are designed so that contact is made on the side of the thread.

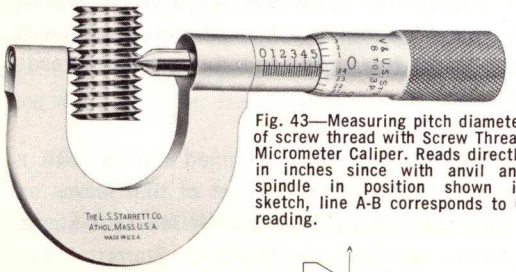
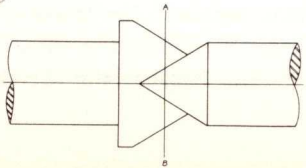



Fig. 43—Measuring pitch diameter of screw thread with Screw Thread Micrometer Caliper. Reads directly in inches since with anvil and spindle in position shown in sketch, line A-B corresponds to 0 reading.



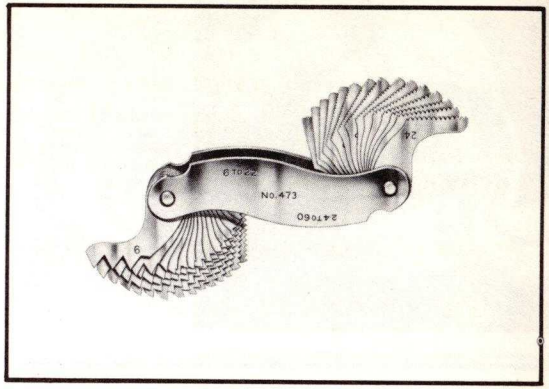



Fig. 42—Screw Pitch Gage measures 30 pitches —V, American National and U. S. Standard 60° threads.

## MEASURING ANGLES

**PROTRACTORS.** Measuring the angular relationship of two or more lines or, as it is termed, "reading the angles," can be performed with a variety of tools depending upon the degree of exactness and the job in hand. For simple angles, a common pro-

tractor will serve, this being either semi-circular or rectangular in shape but with a half circle (180°) graduated in degrees so that angles can be measured or laid out. The rectangular shape has the advantage that any one of four edges can be used as a vertical or horizontal line of reference.

**BEVELS.** For comparing or checking angles, a bevel serves the same purpose as a steel square for rectangles. It consists of a stock and pivoted blade joined by a locking screw. The bevel can be set to a protractor and used as a gage when turning angles on a lathe or the stock and blade can be locked to transfer any angle from the work to a protractor. The addition of an auxiliary blade results in a combination bevel, a more versatile and adaptable tool.

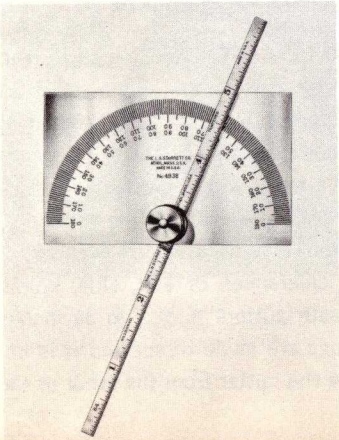


Fig. 44 — This Protractor measures angles from 0 to 180 degrees and also can be used as depth gage.

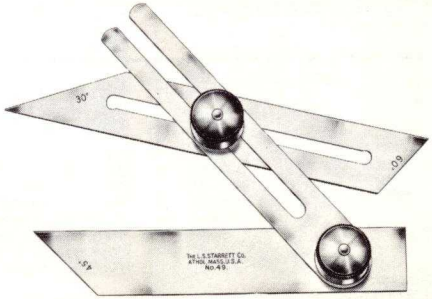


Fig. 45—Combination Bevel for measuring angles.

**BEVEL PROTRACTORS.** A protractor and bevel are combined for greater convenience in the universal bevel protractor. It consists of a graduated disk with a fixed blade and an adjustable stock. With this tool, any angle may be laid off or measured by reading the angle of stock and blade as shown on the protractor scale in degrees. By means of a Vernier and ultra-fine adjustment, it is possible to accurately read angles to 5 minutes or $\frac{1}{12}$ of a degree. Extremely close angular measurements to accuracies as close as $\frac{1}{4}$ second can be accomplished by means of angle gage blocks described on pages 55, 56.

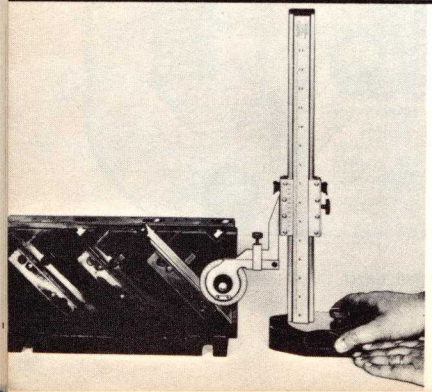


Fig. 46 — Checking angle with Universal Bevel Protractor mounted on Vernier Height Gage on surface plate.



## MISCELLANEOUS TOOLS

**DRILL POINT GAGES.** Accurate holes can be drilled only when drill points are ground accurately. When properly sharpened, each lip of a drill is the same length and has the same angle in relation to the axis of the drill. A drill point gage should be used to check lip angle and length of all drills not sharpened with a precision grinding machine. The gage consists of a blade and sliding head with the head set at the correct angle of 59° and graduated to compare lip lengths to within $\frac{1}{64}$ inch.

**CUTTER CLEARANCE GAGE.** Checking the clearance angle of milling cutters and reamers which may vary from 2 degrees to 15 degrees according to the design is made easy with a cutter clearance gage—consisting of a frame with a protractor section graduated in degrees, an adjustable bar and a pivoted blade, the tool may be used to check either side or peripheral clearances of end, side, spiral, helix or inserted tooth cutters from 2 to 30 inches in diameter. Readings are made direct and it is not necessary to remove the cutter from the arbor of the

milling machine or grinder to check clearance as with other less effective methods.

**A UNIVERSAL PRECISION GAGE** is used to set the cutting tool of a planer or shaper as shown in Fig. 49. This gage with its range of 10¼ inches, fine adjustments, inbuilt level, and scriber and offset attachments can also be used as a surface or height gage, for settings in narrow areas, for gap measurements, face to face, as an adjustable parallel, for transferring settings with indicators, for checking and layout, as a scriber, with gage blocks, etc.

**THICKNESS GAGES.** Thickness or feeler gages are another type of gage having from 6 up to 26 leaves

Fig. 47—Drill Point Gage checks both drill point angle and lip length insuring properly sharpened drills.

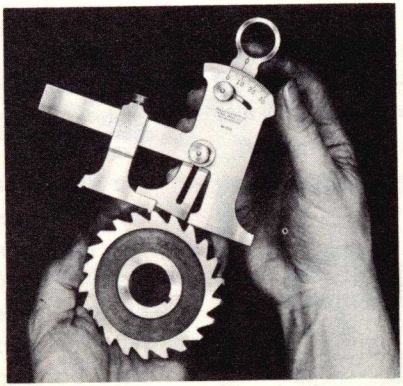


Fig. 48—Checking clearance angle on 22 tooth helical cutter with Cutter Clearance Gage.

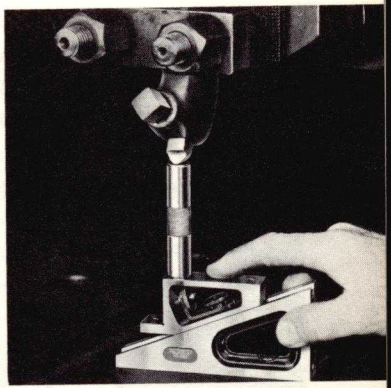


Fig. 49 — By adjusting Universal Precision Gage to a micrometer, height gage or Vernier caliper and then setting cutting tool of planer or shaper to gage, the first cut may be absolutely relied on.

ranging from .0015" to .200" thick. They are mainly used for gaging narrow slots, checking bearing clearance and gear play, and in engine work for fitting pistons, rings and pins and for adjusting tappets, spark plugs and distributor points.

**THICKNESS GAGE STOCK.** Thickness gage or feeler stock also is available in rolls in a rewind dispenser case. A rewind feature permits retracting the stock into the case. Twenty-seven thicknesses from .001" to .025". Stock is snipped off as desired and may be used with a holder. Twelve inch lengths also available.

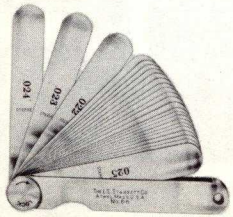



Fig. 50 — This Thickness Gage has 26 leaves from .0015 to .025 inch thick.

Fig. 51—Thickness Gage Stock in rewind dispenser case. Rewind feature permits retracting stock into case.



## VERNIER TOOLS AND HOW TO READ THEM

The Vernier, invented in 1631 by Pierre Vernier, is in effect a combination of steel rules which permits exceedingly accurate readings. The Vernier caliper consists of a graduated steel rule or bar on one end of which is a fixed jaw or contact point. A movable jaw sliding on the bar carries a graduated Vernier plate arranged so that it may be compared with the fixed scale on the bar. Modern Vernier tools, such as the No. 254 and No. 255 Vernier Height Gages and No. 123 Vernier Calipers developed by Starrett, feature an improved big Vernier with 50 divisions instead of the older style with 25 divisions. The 50-division Vernier scale, with widely spaced, easy-to-read graduations and in combination with half as many bar graduations as previous old style instruments, makes possible faster, more accurate and greatly simplified settings and readings without a magnifying glass. Bar and Vernier also have Satin-

Chrome finish for easier reading. Method of reading is described below.

The bar of the tool is graduated in twentieths of an inch (.050"). Every second division represents a tenth of an inch and is numbered. On the Vernier plate is a space divided into fifty parts and numbered 0, 5, 10, 15, 20, 25 . . . . 45, 50. The fifty divisions of the Vernier occupy the same space as forty-nine divisions on the bar.

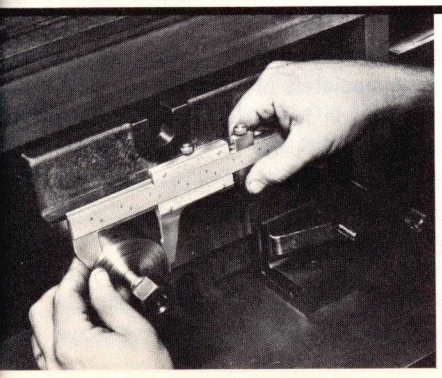


Fig. 52—Taking outside measurement with Master Vernier Caliper. Inside diameters also can be measured without turning tool over.

The difference between the width of one of the fifty spaces on the Vernier and one of the forty-nine spaces on the bar is therefore 1/1000 of an inch (1/50 of 1/20). If the tool is set so that the 0 line on the Vernier coincides with the 0 line on the bar, the line to the right of the 0 on the Vernier will differ from the line to the right of the 0 on the bar by 1/1000; the second line by 2/1000 and so on. The difference will continue to increase 1/1000 of an inch for each division until the line 50 on the Vernier coincides with the line 49 on the bar.

To read the tool, note how many inches, tenths (or .100) and twentieths (or .050) the 0 mark on the Vernier is from the 0 mark on the bar. Then note the number of divisions on the Vernier from 0 to a line which exactly coincides with a line on the bar. EXAMPLE:—In Fig. 53 the Vernier has been moved to the right one and four tenths and one twentieth inches (1.450), as shown on the bar and the fourteenth line on the Vernier coincides with a line, as indicated by the stars, on the bar. Fourteen thousandths of an inch are, therefore, to be added to the

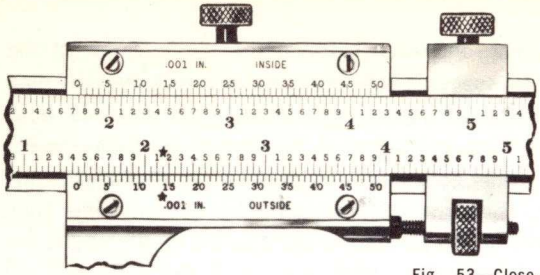



Fig. 53—Close-up of 50-division Vernier. Reading is 1.464".

reading on the bar and the total reading is one and four hundred and sixty-four thousandths inches (1.464).

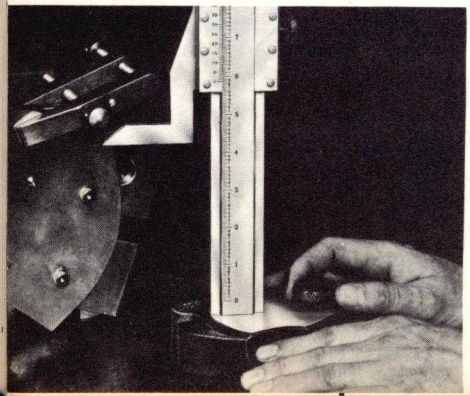


Fig. 54 — This Master Vernier Height Gage has fine adjustment knob on base providing highly sensitive slide adjustment.



The Vernier principle is applied to many tools such as Vernier Height Gages, Vernier Depth Gages, Vernier Protractors, Gear Tooth Vernier Calipers, etc. In the case of Vernier Calipers, scales are provided on the same side of the tool for direct measuring of inside and outside dimensions.

## THE MICROMETER AND HOW TO READ IT

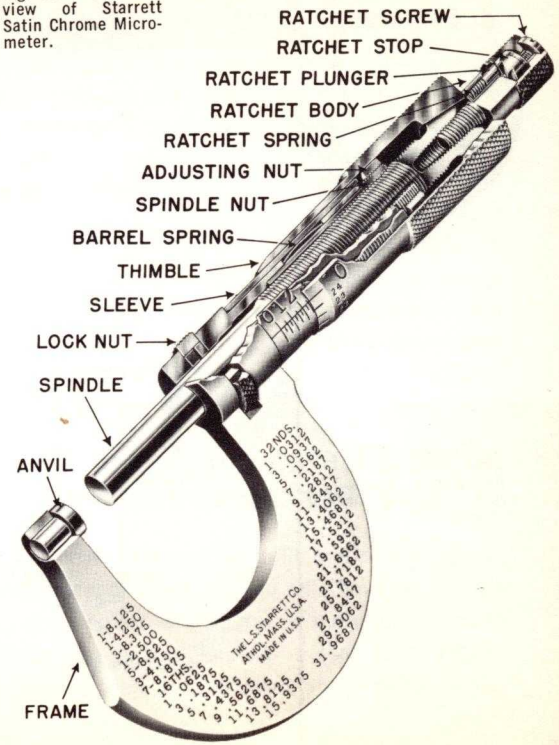
Speak of precision measuring and the average person will think immediately of a micrometer caliper. There is good reason for this popularity, for a micrometer caliper can be used to make a variety of accurate measurements without the possibility of error through misreading which exists when other finely graduated tools are used.

In effect, a micrometer caliper combines the double contact of a slide caliper with a precision

screw adjustment which may be read with great accuracy. It operates on the principle that a screw accurately made with a pitch of forty threads to the inch will advance one-fortieth (or .025) of an inch with each complete turn. As the sectional view shows, the screw threads on the spindle revolve in a fixed nut concealed by a sleeve. On a micrometer caliper of one inch capacity, the sleeve is marked longitudinally with 40 lines to the inch corresponding with the number of threads on the spindle. Every fourth line is made longer and is numbered 1, 2, 3, 4, etc. to indicate one-tenth inch, two-tenths, etc. while other lines are staggered for easy reading.

The beveled edge of the thimble is marked into twenty-five divisions around the circumference and numbered from 0 to 25. When the caliper is closed, only the 0 line on the sleeve can be seen next to the beveled edge of the thimble and the 0 line of the thimble is aligned with the horizontal or axial line on the sleeve. Remembering that every complete revolution of the thimble from 0 to 0 advances or

Fig. 55 — Sectional view of Starrett Satin Chrome Micrometer.



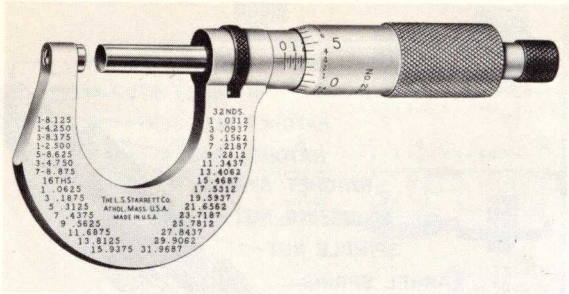
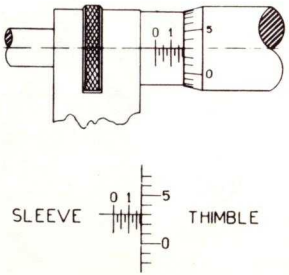



Fig. 56—Micrometer with graduations in thousandths of an inch. Reading is .178".



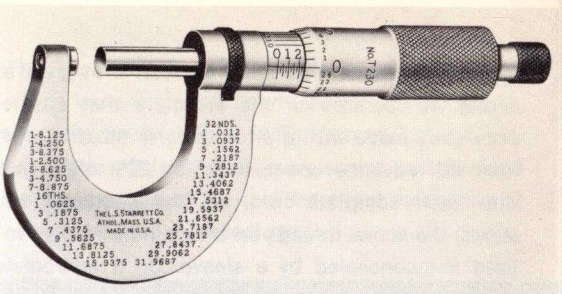
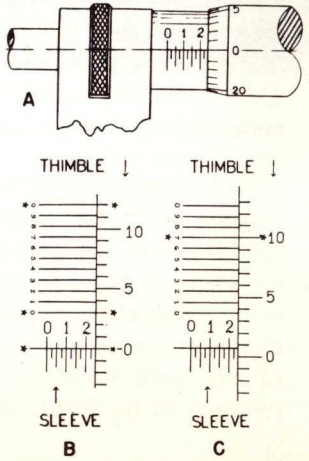




Fig. 57—Micrometer with graduations in ten-thousandths of an inch. Reading in sketch "A" and "B" is .2500"; sketch "C" is .2507".



retracts the spindle one-fortieth (or .025) inch, rotation of the thimble from 0 on the beveled edge to the first graduation will retract the spindle one twenty-fifth of one fortieth, or one twenty-fifth of twenty-five thousandths, which is one thousandth (.001) of an inch.

If you will remember that each numbered graduation on the sleeve represents .1", that each of the other sleeve graduations represent .025", and that each graduation on the thimble represents .001", you will have no trouble reading a micrometer. For example, in Fig. 56, the 1 line is visible which accounts for .100". In addition, there are three more short lines, each representing .025", or combined, .075". On top of that, there are three divisions on the beveled edge of the thimble beyond the 0 mark, each standing for .001" or .003" in all. Adding these up, we have: .100 plus .075 plus .003 equals .178. The reading is .178".

It may help to remember this at first by thinking of the various units as if you were making change. Count the figures on the sleeve as "dollars," the unmarked lines on the sleeve as "quarters" and the lines of the thimble as "cents." Add up your change and put a decimal point instead of a dollar sign in front of the figures.

When the graduations on the sleeve are numbered in the opposite way (from 10 to 0) as on a micrometer depth gage, it should be remembered that the total reading is something less than the lowest graduation visible on the sleeve.

## HOW TO READ TO TEN-THOUSANDTHS WITH A VERNIER MICROMETER

If you have mastered the principle of the Vernier as explained on page 32, you will have no trouble reading a Vernier Micrometer in ten-thousandths of an inch. The only difference is that on a Vernier Micrometer, there are ten divisions marked on the

sleeve occupying the same space as nine divisions on the beveled edge of the thimble. Therefore, the difference between the width of one of the ten spaces on the sleeve and one of the nine spaces on the thimble is one-tenth of a division on the thimble. Since the thimble is graduated to read in thousandths, one-tenth of a division would be one ten-thousandths. To make the reading, first read to thousandths as with a regular micrometer, then see which of the horizontal lines on the sleeve coincides with a line on the thimble. Add to the previous reading the number of ten-thousandths indicated by the line on the sleeve which exactly coincides with a line on the thimble. In figure 57-A&B, the 0 on the thimble coincides exactly with the axial line on the sleeve and the Vernier 0 on the sleeve is the one which coincides with a line of the thimble. The reading is, therefore, an even .2500". In figure 57-C, the 0 line on the thimble has gone beyond the axial line on the sleeve, indicating a reading of more than .2500". Checking the Vernier shows that the seventh Vernier line on the sleeve is the one which exactly coincides with a line on the thimble, therefore, the reading is .2507".

Another type of Starrett Micrometer is also available which gives direct reading in ten-thousandths of an inch without the use of a Vernier.

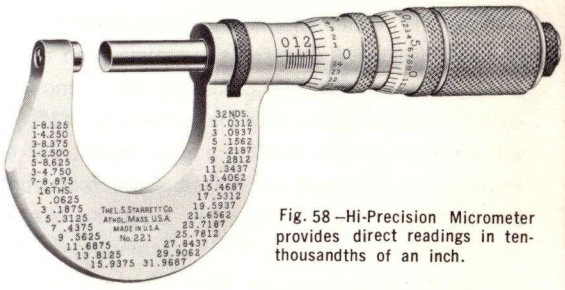



Fig. 58 –Hi-Precision Micrometer provides direct readings in ten-thousandths of an inch.

## MICROMETER TYPES AND FEATURES

**ADJUSTMENT FOR WEAR.** Dirt between the anvil and spindle will cause a micrometer to read incorrectly, but if these surfaces are clean and brought

together carefully and the zero line on the thimble and the axial line on the sleeve fail to coincide, it is apparent that some wear has occurred either in the screw or at the contact surfaces. Readjustment is readily made in Starrett Micrometers by turning the friction sleeve by means of a small spanner wrench until the zeros again agree.

**QUICK MEASUREMENTS.** Micrometers are available with either a friction thimble or ratchet stop so designed that the spindle will not turn after more than a given amount of pressure is applied. This feature is of value when a number of measurements are made or when the measurements are made by more than one person with the same caliper. With the ratchet type, when the anvil and spindle are in proper contact with the work, the ratchet slips by the pawl and no further pressure is applied. The ratchet stop is incorporated in a small auxiliary knurled knob at the end of the thimble. The friction type mechanism is built into the thimble as a thimble friction where it reduces the required span of thumb and fingers and makes it easier to use the micrometer with one hand.

Fig. 59 — By tightening adjusting nut, play is eliminated in spindle nut of micrometer.

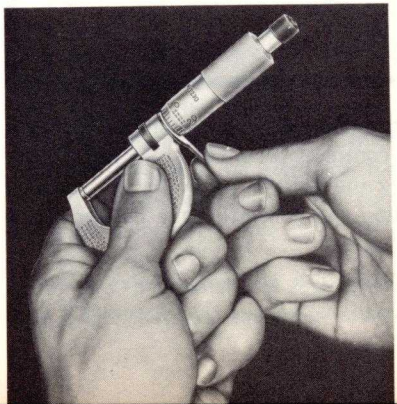


Fig. 60 — Micrometer sleeve is adjustable so that line on sleeve will coincide with zero line on thimble.

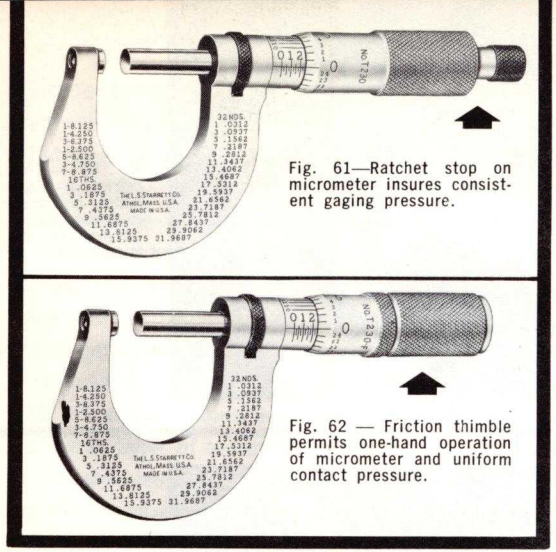



Fig. 61—Ratchet stop on micrometer insures consistent gaging pressure.

Fig. 62 — Friction thimble permits one-hand operation of micrometer and uniform contact pressure.

A constant pressure knurled lock nut (see sectional view, page 35) contracts a split bushing around the spindle, locking the spindle firmly in one position without distortion and converting the caliper into a solid gage.

Many shapes and sizes of Micrometer Calipers are available for special purposes such as: Mul-T-Anvil micrometers with vise-type frame and interchangeable anvils for measuring tubing, hole to an edge, thickness of screw heads; V-Anvil micrometers for checking out-of-roundness of centerless grinding work and measuring odd-fluted cutting tools; disc type micrometers for measuring thin, closely spaced sections; blade type micrometers for measuring circular formed tools and narrow grooves and slots; sheet metal micrometers with deep U frame which permits gaging over beading or flanges or at any point on a surface including near the center of the sheet; screw thread micrometers with pointed spindle and a V-anvil for measuring threads; ball-anvil micrometers and tube micrometers for measuring tubular or curved surfaces; and paper gage micrometers with wide-faced anvil and spindle for measuring the thickness of paper, rubber, cardboard and other soft or resilient materials. Micrometer calipers are also made in a wide range of sizes with capacities up to 60 inches and more.

For service involving continuous hard use or under abrasive conditions, micrometers are available with long wearing tungsten carbide faces of almost dia-

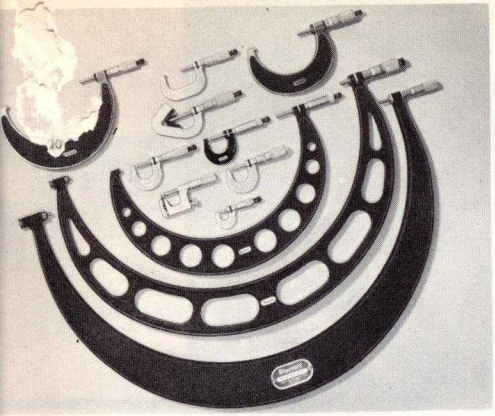


Fig. 63—A few of the many types and sizes of Starrett Micrometers.

Fig. 64—Large diameter in a big flywheel is accurately measured with Inside Micrometer.

mond hardness applied to anvils and spindles. Micrometers are also chromium plated with Satin-Chrome finish to make them stain resisting, longer wearing and to relieve eye strain. Micrometers are made from true stainless steel when tools are needed to be used under extremely corrosive conditions.

**INSIDE MICROMETERS** are an application of the micrometer screw principle to adjustable end measuring gages. The distance between ends or contacts is changed by rotating the sleeve on the micrometer head up to the extent of screw length, usually either one-half or one inch. Greater distances are obtained by means of extension rods and suitable collars or gages which in various combinations cover the total range of the tool.

Inside micrometers are a little more difficult to use than outside micrometer calipers. With spherical

contact points more practice and caution is needed to "feel" the full diametral measurement. Since one contact point is generally held in a fixed position, the other must be rocked in different directions to be sure the tool is spanning the true diameter of a hole or the correct width of a slot.

**END MEASURING RODS.** Precise setting of the slides and table on jig borers and other machine tools are held to a high degree of accuracy by means of precision end measuring rods. Each set consists of two micrometer heads graduated in "tenths" together with a series of hardened, ground and lapped end measuring rods.

**BENCH MICROMETER.** The bench micrometer is a fine precision instrument ideal for bench use either in the shop or inspection laboratory and can be used as a comparator measuring to 50 millionths of an inch (.000050") or for direct measuring to ten-thousandths of an inch (.0001"). Work lengths from 0 to 2 inches can be measured. The base incorporates at the left end a movable anvil which actuates a dial indicator graduated in 50 millionths of an inch (.000050"). The anvil actuates the indicator through a motion transfer mechanism and can be retracted by a lever for repeated measurements. A heavy-duty

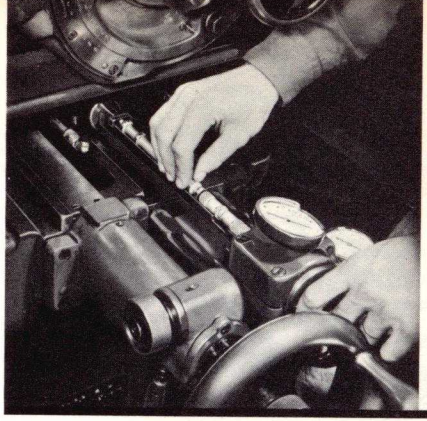


Fig. 65 — Accurate table settings are insured with end measuring rods on this jig borer.

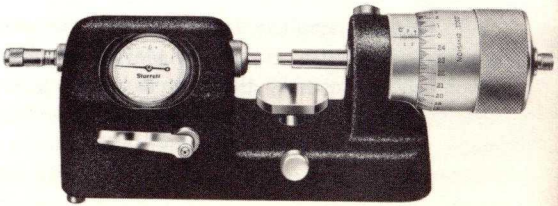


Fig. 66—The Bench Micrometer can be used as a comparator measuring to 50 millionths of an inch or for direct measuring to ten-thousandths of an inch.

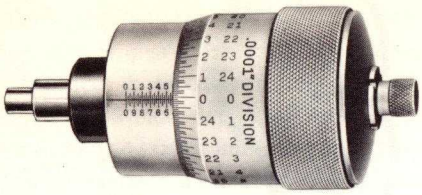



Fig. 67—this micrometer head has 2-1/16" thimble diameter and graduations in ten-thousandths of an inch.

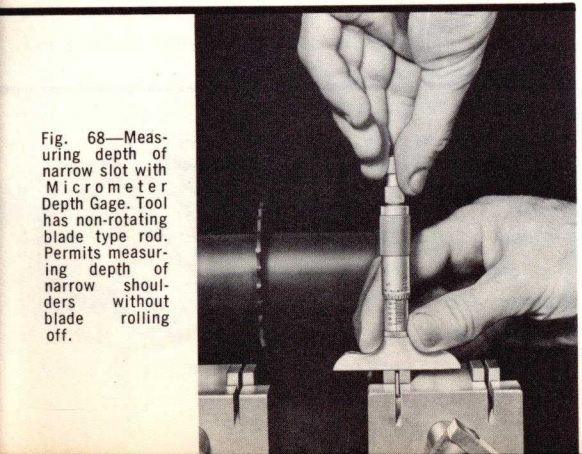


Fig. 68—Measuring depth of narrow slot with Micrometer Depth Gage. Tool has non-rotating blade type rod. Permits measuring depth of narrow shoulders without blade rolling off.

micrometer head mounted at the right end of the base reads directly in ten-thousandths of an inch and has a two-inch range. An adjustable work table is centered beneath the anvil and spindle.

**MICROMETER HEADS.** Electronic applications, machine tools, special gages and tooling often specify micrometer heads where micrometer accuracy in settings and adjustment is required. Available in ranges of 0 to ½ inch, 0 to 1 inch and 0 to 2 inches with graduations in thousandths or ten-thousandths of an inch, with Satin-Chrome finish or made of stainless steel.

**MICROMETER DEPTH GAGES.** Micrometers are also used to measure depth of holes, slots and projections in thousandths of an inch and for this application are called micrometer depth gages. Here is a typical gage of this type measuring the depth of a narrow slot. The blade is flat, only 1/8" wide and does not turn in use. Base is hardened, ground and lapped. Micrometer depth gages are also made with a short half base which permits gaging close to shoulders and between obstructions where ordinary gages can not be used.

## DIAL INDICATORS

One of the most widely used instruments today in layout, inspection and quality control operations is the dial indicator. Specially designed and manufactured to fine watch making standards with either jeweled or plain bearings, the dial indicator has precisely finished gears, pinions and other working parts that make possible measurements from one-thousandth to 50 millionths of an inch, depending on accuracy requirements. Easier maintenance, longer life, and greater accuracy can be expected with the modern dial indicator because of unit-construction and simple, interchangeable design. Fewer parts mean greater efficiency, less friction and wear. Any gear unit and any case assembly can be combined to give a complete dial indicator of the style desired.

The contact point is attached to a spindle and rack whose movement is transmitted to a pinion and then through a train of gears to a hand which sweeps

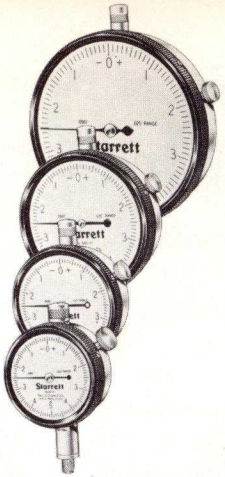


Fig. 69—Typical Starrett Dial Indicators in the four standard American Gage Design sizes.

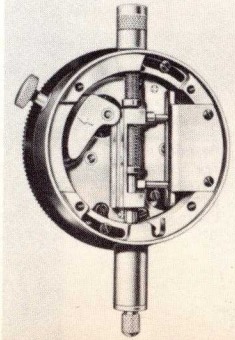


Fig. 70 — Non-shock mechanism in a Starrett Dial Indicator.

the dial of the indicator. A small movement of the contact is thus greatly magnified and read directly from the dial in thousandths or as close as 50 millionths of an inch, depending on the type of indicator used. Long range indicators have direct reading count hands and a double dial. Graduations are available for reading in .001", .0005", .00025", .0001", and .00005"—with ranges from 12" down to .003". Dials can have balanced or continuous graduations.

When the dial indicator is subject to sudden blows or shock, a NONSHOCK mechanism can be furnished in most indicators in place of the regular mechanism. Impact and shock are completely absorbed and isolated from the gear movement. Any regular dial indicator can also be converted into non-shock type by replacing the regular contact points with a shock absorbing anvil unit. The regular contact point may be replaced with contacts of almost any shape or length to suit the work. These include contact points of extra length, special form, tapered, and a roller contact for use on moving material.

Many useful attachments are available to suit work requirements. Dial indicators can be furnished with tolerance hands; with special dials; with rubber dust guards to seal out dust and foreign matter; with antimagnetic mechanisms when the dial indicator is used near magnetic fields; with long stems up to 12 inches for use in deep holes; with lever control for lifting the indicator spindle.

Super precision dial indicators with graduations in 50 millionths of an inch and accuracy to plus or minus 10 millionths are also available. These are used for applications requiring extreme precision such as in shop inspection to laboratory standards or in laboratory work. The long range dial indicator with ranges of 2, 3, 4 or 5 inches and on up to 12 inches makes possible all types of long range gaging such as on jig and fixture work, for production measuring on machine tools or as precision stops. Count hands and double dials permit direct reading in thousandths of an inch.

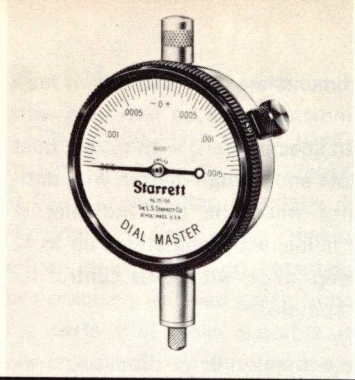



Fig. 71 — This Starrett Super Precision Dial Indicator is graduated in 50 millionths of an inch and has accuracy of ± .00001".

**DIAL GAGES.** The principle of direct reading from a pointer and graduated dial provides both the accuracy and the speed of reading essential in many of today's inspection operations, and consequently, the dial indicator has been incorporated in all types of special and standard gaging equipment, as well as in many machine tools. Some gages are direct reading and others serve as comparators showing plus or minus variations in size.

**DIAL COMPARATORS.** The dial comparator is used for inspecting duplicate parts and various materials, either in bench inspection or on the production line. The precision ground base accommodates all types of work as well as V-blocks and fixtures. A dial indicator with fine setting adjustment is mounted on an adjustable bracket on a vertical post. A hand lever operates the indicator to contact the work and size variations are read from the dial.

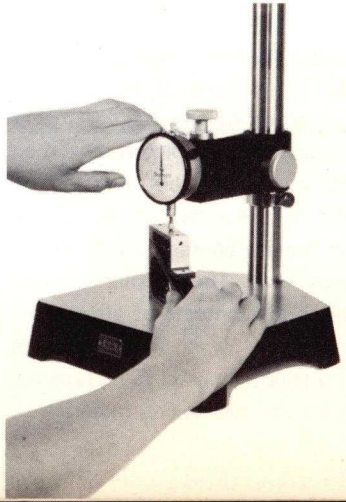


Fig. 72 — The Dial Comparator is used for inspection operations, in toolrooms and machine shops on a wide variety of applications.

**DIAL TEST INDICATORS.** The dial test indicator is an all-purpose tool used in layout, inspection and on machine tools for truing up work, checking runout, concentricity, straightness, surface alignment, and for transferring measurements. A dial indicator is mounted at the end of a horizontal arm adjustable on an upright base post. The post is adjustable on a slotted base. Another test indicator is the universal dial test indicator. Various attachments, including a tool post holder, adapt it to a wide range of applications, such as checking runout of a spindle turned on a lathe.

**LAST WORD INDICATORS.** One of the most flexible test instruments is the LAST WORD dial test indicator. A typical application is with a Vernier height gage on a surface plate for comparing measurements from gage blocks with the work. This type of test indicator has a jeweled lever for smooth movement,

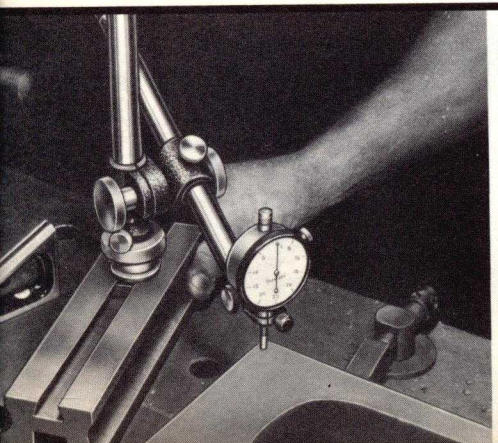


Fig. 73—Planer operator uses Heavy Duty Dial Test Indicator to check depth of cut on flat casting.

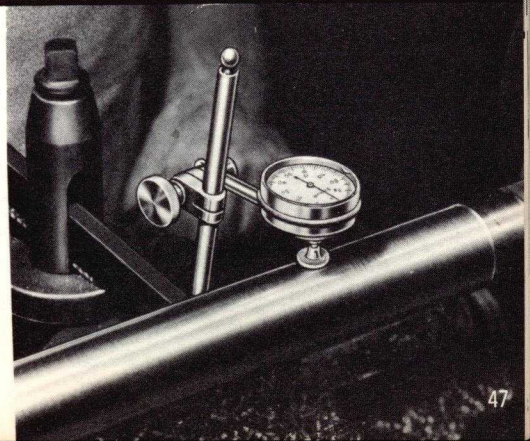


Fig. 74 — For a quick check of runout, lathe operator uses Universal Dial Test Indicator mounted in tool post.

reversible action, swivel body and hard chrome plated contact.

**MAGNETIC BASE INDICATORS.** A magnetic base indicator holder greatly increases the usefulness and application of the dial indicator on all shop set-up, checking, and inspection jobs. The time usually spent in clamping the indicator to a machine is eliminated since its powerful, permanent magnet base holds to any steel or iron surface—horizontally, vertically or upside down. A push button turns the magnetic force on or off. Available with various indicators and holding arrangements to suit the work. Especially useful is the Flex-O-Post indicator holder when used with the magnetic base. Complete flexi-

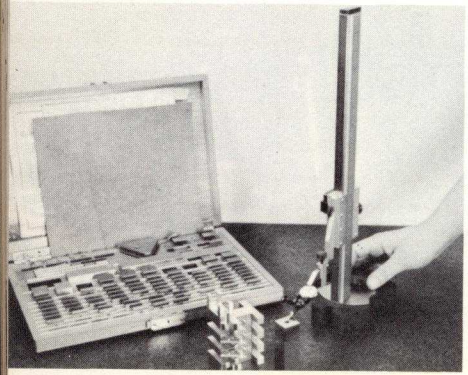


Fig. 75 — Last Word Dial Test Indicator attached to Vernier height gage on surface plate for comparing measurements from gage blocks with the work.

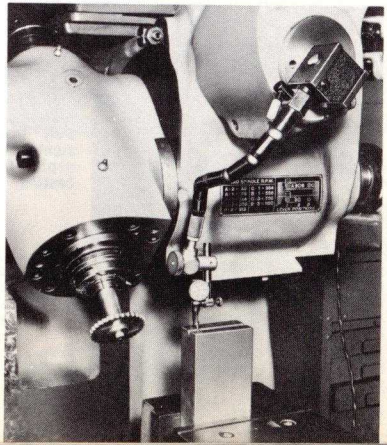


Fig. 76—Flex-O-Post Holder with magnetic base and Last Word Indicator checking groove in milling operation.

bility of the post permits use of the indicator in awkward, hard-to-reach positions impossible to reach by conventional indicator holding devices.

**OTHER DIAL GAGES.** Many other types of dial gages are also available for use on a great variety of work, such as portable dial indicator hand gages, pocket gages, sheet gages, depth gages, inside gages, crankshaft or distortion gages, cylinder gages and out-of-roundness gages.

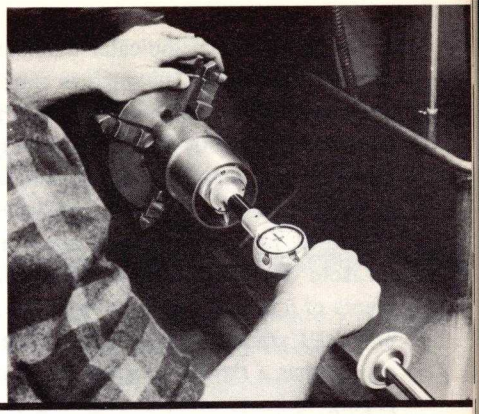


Fig. 77 — Inspecting bore size in tenths during grinding operation with Dial Bore Gage.

**DIAL BORE GAGES.** Another gage is the dial bore gage used for precision gaging of cylindrical bores. The dial bore gage quickly inspects hole diameters and will detect and measure any variation from a true bore, such as taper, out-of-roundness, bell-mouth, hour-glass or barrel shapes. Basically, the gage consists of a contact head, an indicator housing and handle. An adjustable range screw plus two centralizing plungers give the gage 3-point contact to insure true alignment. The gaging contact actuates a nonshock dial indicator direct reading in half-thousandths or ten-thousandths of an inch. Models are available with ranges from 3 to 12⅛ inch diameter and 6 to 7 inch bore depths.

**DIAL INDICATOR DIAMETER GAGES.** When the work is varied and involves many large diameters up

to 60 inches, a dial indicator diameter gage of this type is often used. The gage is extremely versatile and adaptable to a wide range of gaging jobs without need of many, costly special-purpose gages. Uses include internal and external checking of shallow diameters, roundness, concentricity, grooves, recesses, shoulders, tapers. Eight gage sizes are available to measure diameters from 12 to 60 inches in increments of 6 inches. Indicator reads to .0005" but .001 and .0001 graduations are also available. This type of gage has a rigid box-section beam and adjustable gaging contacts at each end. The sensitive gaging contact transfers work dimension through a friction-free motion transfer mechanism to a direct reading dial indicator. The gage is loaded for either I.D. or O.D. measurements by moving a single lever. A setting master is available for use with this gage and also a heavy-duty diameter gage.

**SPECIAL GAGES.** If the work cannot be gaged with standard equipment because of special shape or

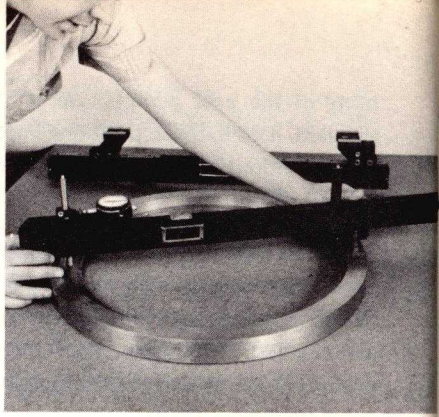


Fig. 78—Checking large diameter with Dial Indicator Diameter Gage.

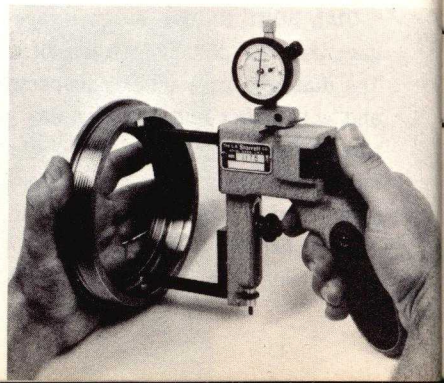


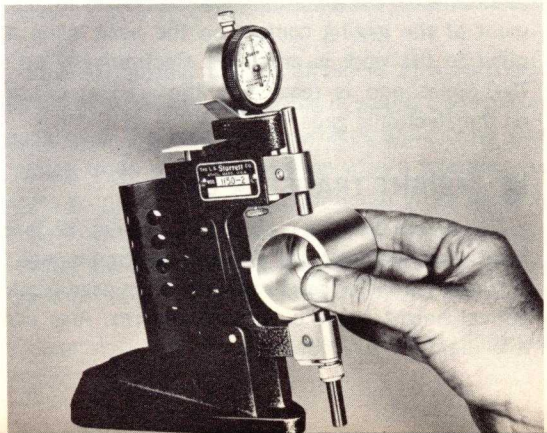
Fig. 79—Groove size is read directly from dial indicator on this Dial Indicator Internal Groove Gage. Jaw with gaging contact is retracted by thumb retractor.

size, it is often necessary to build special tools and gages to check the work.

**DIAL INDICATOR INTERNAL GROOVE GAGES.** A fast, accurate way to measure the inside diameter of grooves of all types is by means of the dial indicator internal groove gage. The gage has adjustments to handle a range of diameters from .375 up to 6 inches and eliminates the need for expensive gages for every job. The gage consists of a pistol-grip frame with a sensitive jaw and adjustable reference jaw, both with hard chrome gaging contacts. The sensitive jaw is retracted with parallel retraction by a thumb lever, permitting inserting the gage in the work. Work dimension is transferred through a motion-transfer mechanism to a dial indicator reading in .0005".

**DIAL INDICATOR SNAP GAGES.** This snap gage also uses a dial indicator for direct reading of variation in diameter in tenths of a thousandth of an inch. The gage is made in four models to cover a work range up to 8 inches diameter. The gage has a light, rigid "C" frame with insulating handle and two adjustable gaging contacts. The upper sensitive contact transfers work dimension through a motion transfer mechanism to a dial indicator.

Fig. 80—Inspecting outside diameter with Dial Indicator Snap Gage. Gage can be used separately or on bench stand as shown.



## ELECTRONIC GAGES

Electronic gages represent the "Last Word" in ultraprecision gaging. The model shown reads in ten millionths of an inch (.00001") or ten-thousandths of an inch (.0001") and features a dual-purpose differential amplifier. This permits use as an electronic height gage or comparator; also for differential inspection of length, thickness, diameter, flatness, taper and concentricity.

Electronic gaging heads held by a height transfer gage (see Fig. 82) or other devices are used in conjunction with the electronic gage. Mechanical movement of the gaging contact on the head when applied to the work is amplified electronically up to 7000 times and is read from the graduated scale on the electronic gage.

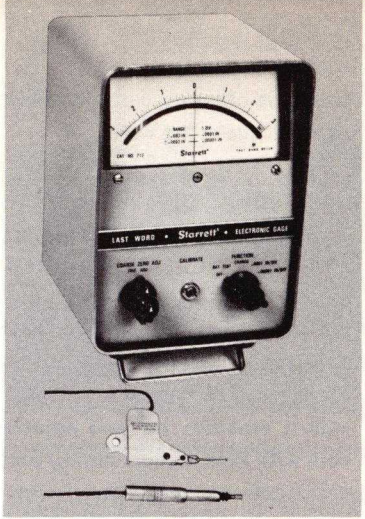



Fig. 81 — For ultra - precision gaging, the Electronic Gage is used. Electronic gaging heads are shown in the foreground.

## HEIGHT TRANSFER GAGE

The height transfer gage shown in Fig. 82 is an ideal instrument for use with the electronic gage to accurately transfer height settings from gage blocks, optical height gages or other standards. Also used with dial type test indicators.

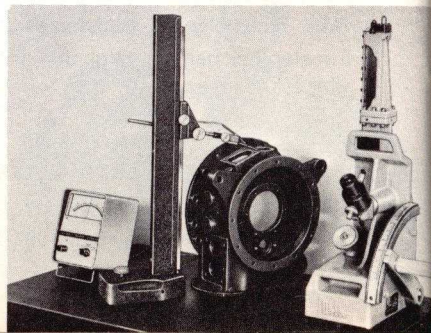


Fig. 82—Checking height of machined face on a housing using Starrett Height Transfer Gage and Electronic Gage. Gage is set to height within .00005" from Starrett-Webber Optical Height Gage.

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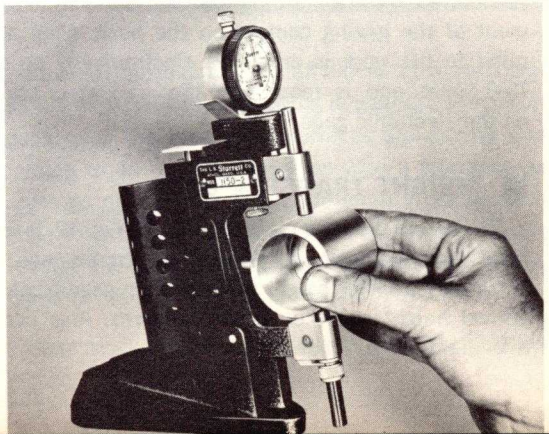

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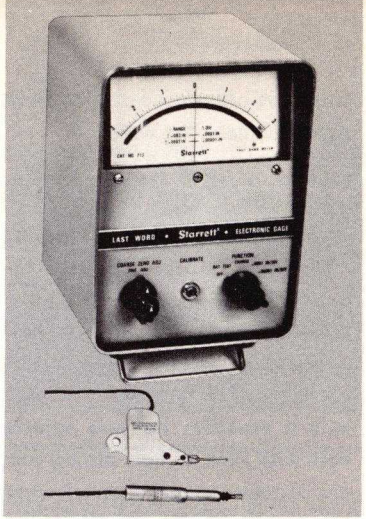


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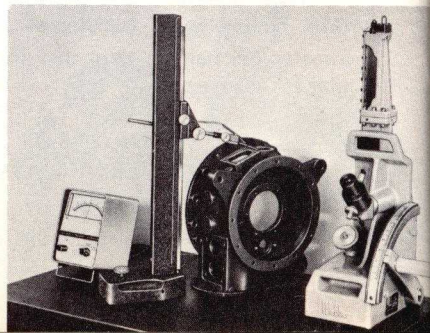


Fig. 82—Checking height of machined face on a housing using Starrett Height Transfer Gage and Electronic Gage. Gage is set to height within .00005" from Starrett-Webber Optical Height Gage.

## GAGE BLOCKS

The International Standard for measurement is the light wave, and the International Inch as well as the International Meter are now established in terms of the wavelength of monochromatic light (light having a single wavelength) emitted from Krypton 86 gas. The length of a single wave from this gas is 0.0000238 inches and gives us an absolute standard which never changes.

Light waves, of course, cannot be handled like a micrometer or Vernier caliper, but they are used to establish the length of physical standards having accuracy in millionths of an inch. These standards are called gage blocks.

Gage blocks are the industrial standards of length used for calibrating precision measuring instruments, verifying the accuracy of inspection gages and other types of masters, checking accuracy of tools, setting gages and tools, laying out tools and fixtures and inspecting parts in process or finished parts.

Fig. 83 — A 3-inch Gage Block. This Starrett-Webber Croblox® is made of solid chrome carbide, almost diamond hard and practically corrosion proof.

Essentially, they consist of blocks of a hard and stable material with measuring or gaging surfaces on each end. The measuring surfaces are ground and lapped to an overall dimension with a tolerance as close as plus or minus one millionth of an inch. In order to obtain the desired length, blocks of different lengths are selected from a set of blocks and "wrung together" to form a stack of blocks.

Gage blocks are made in several grades or degrees

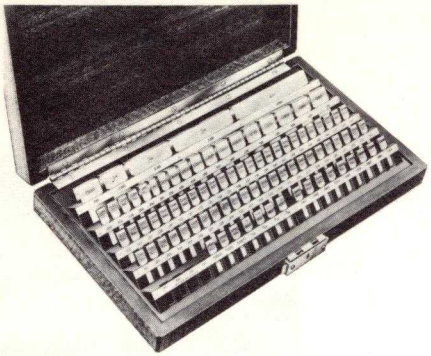


Fig. 84—This set of 88 Gage Blocks consists of rectangular Croblox® in sizes from .1001" through 4.000".

of accuracy—"grand master," "master," and "working" grades. "Grand master" blocks control the accuracy of an entire manufacturing operation and their principal use is to certify the accuracy of "master" blocks. Such blocks are ultra accurate. For example, Starrett-Webber Laboratory Master Gage Blocks have a length tolerance of plus or minus one millionth of an inch. "Master" blocks are used to check the accuracy of the "working" blocks which are used in the shop.

Starrett-Webber "master" blocks are designated as "AA" and have a length tolerance of plus or minus two millionths of an inch. Their "working" grades are "A+" with a tolerance of plus four, minus two millionths of an inch, and "A" with a tolerance of plus six, minus two millionths of an inch.

Various materials are available. Webber CROBLOX®, the world's finest, are made of chrome carbide—long wearing, almost diamond hard and corrosion proof—and maintain accuracy many times longer than steel blocks. CROBLOX® are available in "Laboratory Master," "AA," and "A+" grades. Webber steel blocks are available in "AA," "A+," and "A" grades. Various types are also available—rectangular, square and heavy duty. The use of gage blocks is greatly extended by means of attachments which can be assembled with the blocks to build height gages, snap gages, scribers and dividers.

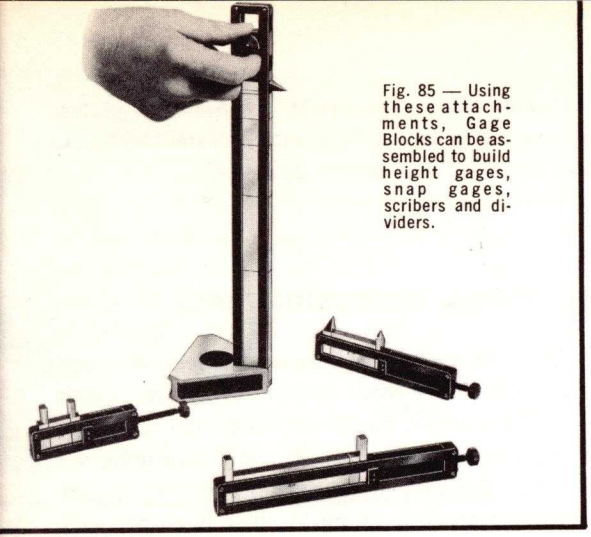


Fig. 85 — Using these attachments, Gage Blocks can be assembled to build height gages, snap gages, scribers and dividers.

## ANGLE GAGE BLOCKS

Angle gage blocks furnish fast, very simple and extremely accurate measurements of any angle. They're far superior to sine bar measuring methods, which involve trigonometric formulae and complicated stacks of rectangular gage blocks.

A set of Starrett-Webber angle gage blocks consisting of only 16 blocks will measure 356,400 angles in steps of one second, to an accuracy of 1/5,000,000th of a circle! The reason is because these micro-accurate blocks are so designed that they can be used in either plus or minus positions.

For instance, to obtain a measurement of 35° you simply take the 30° angle and add the 5° angle, making sure that both plus ends are together. To get a measurement of 25°, you use the same two blocks

Fig. 86 — A set of Webber Angle Gage Blocks. They permit fast, extremely accurate measurement of any angle and are far superior to sine bar measuring methods.

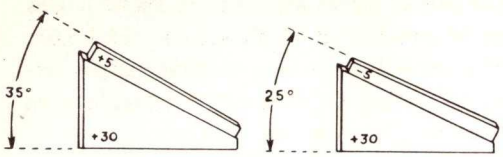



Fig. 87—Sketches illustrate how angles of 35° and 25° can be obtained using only two Angle Gage Blocks.

but wring them together so that the minus end of the 5° block is over the plus end of the 30° block. This will subtract 5° from 30°, thus giving your 25° measurement. Any size angle can be quickly and easily obtained in this manner, using only a few blocks in the proper combination of plus and minus positions. See Fig. 87.

Webber angle gage blocks are available in two accuracies: ¼ second "Laboratory Master" accuracy, and 1-second "Tool Room" accuracy.

## OPTICAL MEASURING TOOLS

Optics are also extensively used in high precision measuring. The Webber optical height gage shown right, for example, combines two proven principals of measurement—gage blocks and a measuring microscope. Basically, it consists of a "stack" of gage blocks permanently wrung together to an accuracy of +.000005" per inch of height. Measurements are read in the optical eyepiece of the microscope. Other optical tools include optical flats, optical flat parallel sets, optical polygons for checking and calibrating angles, and optical flat targets. Optical flats, shown right, are used for checking flatness of lapped surfaces in millionths of an inch.

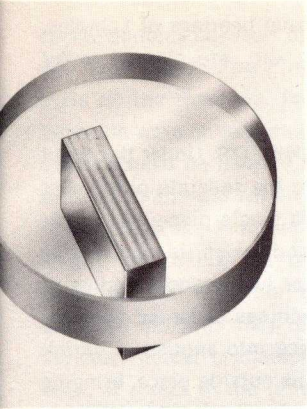


Fig. 89 — Fused Quartz Optical Flats provide a quick, extremely accurate means of checking flatness of lapped surfaces.

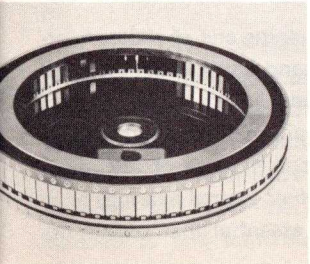


Fig. 90 — Optical Polygons are used for checking and calibrating angles to extreme accuracy.

Fig. 88—Webber Optical Height Gage for high precision measuring. Gage uses gage blocks in combination with a measuring microscope.

## FACTS ABOUT FITS

In machine construction many of the parts bear such a close and important relation to one another that a certain amount of hand fitting is essential to make the surface contacts as they should be. If the surfaces in contact are to move on each other, the fit is classed as a sliding or running fit. If the surfaces are to make contact with sufficient firmness to hold them together under ordinary use, the fit is classed either as a driving, shrink, or forced fit.

**SLIDING FITS.** Under this head may be classed the fitting of cross and traversing slides of lathes, milling machines, drilling machines, boring machines, grinding machines and planers. These fits are usually obtained by scraping. In most of these fits the moving and stationary parts are held in contact with each other by means of adjustable contact strips or gibs. In some cases, such as the tables of grinding and of planing machines, their weight keeps them in sufficiently close contact.

**RUNNING FITS.** The journal bearings of spindles, crank shafts, line shafting, etc., are classed under this heading.

**FORCED FITS AND SHRINK FITS.** Under this head are classed those fits where the separate parts must act in use as if they were a single piece: as, for example, the crank pins and axles in locomotive driving wheels or the cutter heads and spindles of numerous woodworking machines. A forced fit is obtained by pressing one piece into another. A shrink fit is obtained by heating the outside piece, bringing it into proper relationship with the inside piece and allowing it to shrink into position as it cools.

**LIMITS.** In the case of running and of sliding bearings, a certain amount of hand fitting is necessary to obtain desired results, and in all cases certain limiting requirements prevail. In sliding and running bearings the limits are usually those of alignment and of contact, while in either journal bearings or in flat sliding bearings it is essential that certain ac-

curate contact between the surfaces shall be made, and there will also be a limit of alignment with other parts of the machine. For example, in the engine lathe the ways or vees and the cross slide of the tool carriage must be parallel to or at right angles to the axis of the spindle within set limits. In engine lathe construction the limit set for this is 0.001" in a foot length. In testing the parts, use is made of the Universal Test Indicator with the hand reading on a dial. The indicator may be held by a magnetic base indicator holder or clamped to a test bar, a straight edge, or direct to the lathe spindle; also, if desired, it can be and often is held upon a special slider stand fitted to the vees of the machine.

In the making of shrinkage and forced fits the limits are usually those of size. The amount of pressure necessary to place the two parts together is the limiting factor in the case of forced fits. In forcing the axles into locomotive driving wheels, the specifications may limit the pressure to between one hundred to one hundred and fifty tons. However specified, it in fact reduces to limits of size and the use of measuring tools.

**AMOUNT TO LEAVE.** Where pins, spindles, etc., are to be forced into holes, or where collars, hubs, flanges, and other machine parts are to be shrunk on to spindles, it is customary to make the diameter allowance upon the spindle rather than upon the hole. The amount which it is necessary to add to the spindle or shaft diameter must of necessity vary with the length and diameter of the hole, the metals used, and the form of the surrounding hub. The tables on the following page show the tolerances used by one manufacturer.

## LIMITS OF TOLERANCE

While it is possible to produce machine parts with measurements refined to any degree of accuracy, extreme precision in some cases may prove too costly for commercial work.

# ALLOWANCES FOR DIFFERENT CLASSES OF FITS

(Newall Engineering Co.)

| Class | Nominal Diameters | Tolerances in Standard Holes* Up to ½" | ⅝"–1" | 1 1/16"–2" | 2 1/16"–3" | 3 1/16"–4" | 4 1/16"–5" |
|---|---|---|---|---|---|---|---|
| A | High Limit ..... | +0.0002 | +0.0005 | +0.0007 | +0.0010 | +0.0010 | +0.0010 |
| | Low Limit ..... | —0.0002 | —0.0002 | —0.0002 | —0.0005 | —0.0005 | —0.0005 |
| | Tolerance ..... | 0.0004 | 0.0007 | 0.0009 | 0.0015 | 0.0015 | 0.0015 |
| B | High Limit ..... | +0.0005 | +0.0007 | +0.0010 | +0.0012 | +0.0015 | +0.0017 |
| | Low Limit ..... | —0.0005 | —0.0005 | —0.0005 | —0.0007 | —0.0007 | —0.0007 |
| | Tolerance ..... | 0.0010 | 0.0012 | 0.0015 | 0.0019 | 0.0022 | 0.0024 |
| | Allowances for Forced Fits | | | | | | |
| F | High Limit ..... | +0.0010 | +0.0020 | +0.0040 | +0.0060 | +0.0080 | +0.0100 |
| | Low Limit ..... | +0.0005 | +0.0015 | +0.0030 | +0.0045 | +0.0060 | +0.0080 |
| | Tolerance ..... | 0.0005 | 0.0005 | 0.0010 | 0.0015 | 0.0020 | 0.0020 |
| | Allowances for Driving Fits | | | | | | |
| D | High Limit ..... | +0.0005 | +0.0010 | +0.0015 | +0.0025 | +0.0030 | +0.0035 |
| | Low Limit ..... | +0.0002 | +0.0007 | +0.0010 | +0.0015 | +0.0020 | +0.0025 |
| | Tolerance ..... | 0.0003 | 0.0003 | 0.0005 | 0.0010 | 0.0010 | 0.0010 |
| | Allowances for Push Fits | | | | | | |
| P | High Limit ..... | —0.0002 | —0.0002 | —0.0002 | —0.0005 | —0.0005 | —0.0005 |
| | Low Limit ..... | —0.0007 | —0.0007 | —0.0007 | —0.0010 | —0.0010 | —0.0010 |
| | Tolerance ..... | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0005 |
| | Allowances for Running Fits† | | | | | | |
| X | High Limit ..... | —0.0010 | —0.0012 | —0.0017 | —0.0020 | —0.0025 | —0.0030 |
| | Low Limit ..... | —0.0020 | —0.0027 | —0.0035 | —0.0042 | —0.0050 | —0.0057 |
| | Tolerance ..... | 0.0010 | 0.0015 | 0.0018 | 0.0022 | 0.0025 | 0.0027 |
| Y | High Limit ..... | —0.0007 | —0.0010 | —0.0012 | —0.0015 | —0.0020 | —0.0022 |
| | Low Limit ..... | —0.0012 | —0.0020 | —0.0025 | —0.0030 | —0.0035 | —0.0040 |
| | Tolerance ..... | 0.0005 | 0.0010 | 0.0013 | 0.0015 | 0.0015 | 0.0018 |
| Z | High Limit ..... | —0.0005 | —0.0007 | —0.0007 | —0.0010 | —0.0010 | —0.0012 |
| | Low Limit ..... | —0.0007 | —0.0012 | —0.0015 | —0.0020 | —0.0022 | —0.0025 |
| | Tolerance ..... | 0.0002 | 0.0005 | 0.0008 | 0.0010 | 0.0012 | 0.0013 |

*Tolerance is provided for holes, which ordinary standard reamers can produce, in two grades, Classes A and B, the selection of which is a question for the user's decision and dependent upon the quality of the work required; some prefer to use Class A as working limits and Class B as inspection limits.

†Running fits, which are the most commonly required, are divided into three grades: Class X for engine and other work where easy fits are wanted; Class Y for high speeds and good average machine work; Class Z for fine tool work.

To avoid waste of time, labor, and money, the following may be considered a representative set of rules to be used when experience and familiarity with the work do not indicate the exact limits to use. They define the degree of accuracy to be expected in those cases where specifications and drawings do not call for greater precision than the rules provide for.

(1) Full information regarding the limits of tolerance should be clearly shown by drawing submitted, or be definitely covered by written specifications to which reference must be made by notations on the drawings.

(2) Where the customer fails to supply proper data as to limits, the supplier will use his best judgment in deciding just what limits it may be advisable to work to. The supplier will not, in any event, assume responsibility for possible excessive cost brought about through working to closer limits than may be necessary, nor permitting greater latitude than may subsequently be found to be proper.

(3) Where dimensions are stated in common fractions (½, ¼, ⅛, etc.) with no limits of tolerance specified, it will be assumed that a considerable margin for variations from figured dimensions is available. Unless otherwise ordered, the supplier will proceed according to the dictates of his best judgment as to what limits should be taken.

(4) For all important dimensions Decimal figures should be used and limits clearly stated on detail drawings. If Decimal figures are not used for such dimensions, a notation referring to the degree of accuracy required must be placed prominently on the drawing.

(5) It is frequently necessary to reduce fractions representing fourths, eighths, sixteenths, thirty-seconds, and sixty-fourths to decimal equivalents. When a dimension of this character is expressed in a decimal equivalent and carried out to three, four,

The rake of the teeth should be such that the blade will cut on the forward stroke. The cutting stroke, using the same motion as in filing, should be sufficiently firm to assure a cut rather than a slide. The pressure should always be lifted on the return stroke. Forty to fifty strokes a minute should be the maximum.

Using power hacksaw machines, strokes vary from 60 to 150 per minute, blade pressure from light to heavy, depending on material cut. See Page 66.

Hacksaw hand and power blades are made in a wide range of lengths, widths, thicknesses and teeth per inch to suit cutting requirements and are available in standard or high speed steel. For more useful data on hacksaws see the following pages.

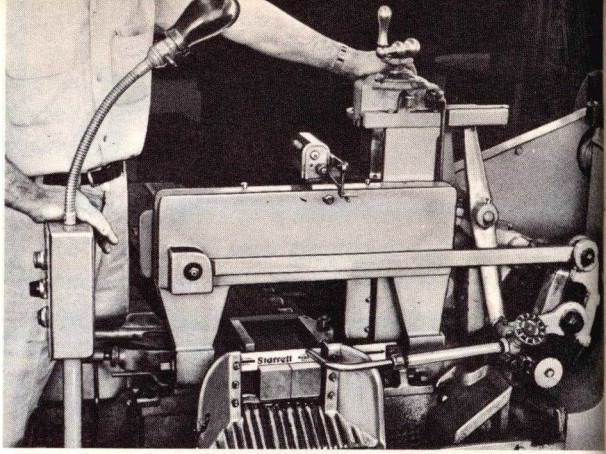
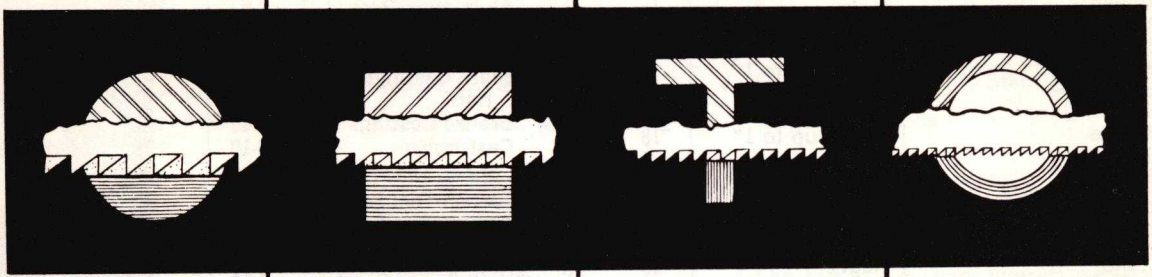


Fig. 93—Power hacksaw machines are used for production work.

Fig. 94—For cutting clean, round holes, Hole Saws are commonly used either in portable power tools or machine tools.

## GENERAL RULES GOVERNING HACKSAW BLADE SELECTION

| A. Mild Materials In Large Sections | B. Harder Materials In Large Sections | C. Unusual Work Shapes | D. Pipes, Tubing, Conduit |
|---|---|---|---|
|  | | | |
| Choose coarse tooth blade to provide plenty of chip clearance, faster cutting. | Choose blade with finer teeth than in A to distribute cutting load over more teeth while still maintaining good chip clearing action. | Choose blade to always keep two or more teeth in contact with narrowest section. Coarse tooth blades stradle work, strip out teeth. | Choose blade with finest teeth per inch to keep two or more teeth in contact with wall. Keep inside of work free of chip accumulation. |
| Hand Blades—<br>14 Teeth Per Inch | Hand Blades—<br>18 Teeth Per Inch | Hand Blades—<br>24 Teeth Per Inch | Hand Blades—<br>32 Teeth Per Inch |
| Power Blades—<br>4 to 6 Teeth Per Inch | Power Blades—<br>6 to 10 Teeth Per Inch | Power Blades—<br>10 to 14 Teeth Per Inch | Power Blades—<br>14 Teeth Per Inch |

## Material Cutting Chart
## Hand Hacksaw Blades

| Material | Type | Teeth per Inch |
|---|---|---|
| Aluminum | Solids | 14 |
| Angles | Heavy | 18 |
| Angles | Light | 24 |
| Babbitt | | 14 |
| Brass | Solids up to 1" | 18 |
| Brass Pipe | | 24 |
| Brass Tubing | | 24 |
| Bronze | Solids up to 1" | 18 |
| BX Cable | Heavy | 24 |
| BX Cable | Light | 32 |
| Cast Iron | Up to 1" | 18 |
| Channel | Heavy | 18 |
| Channel | Light | 24 |
| Cable | Heavy | 18 |
| Copper | Solids up to 1" | 14 |
| Drill Rod | Over ¼" | 18 |
| Drill Rod | No. 30 to ¼" | 24 |
| Drill Rod | No. 30 and smaller | 32 |
| General Purpose Cutting | | 18 |
| Iron Pipe | | 24 |
| Metal Conduit | | 24 |
| Sheet Metal | Over 18 gage | 24 |
| Sheet Metal | Under 18 gage | 32 |
| Steels | ¼" to 1" | 18 |
| Steels | ¼" and under | 24 |
| Tubing | Over 18 gage | 24 |
| Tubing | Under 18 gage | 32 |

## Material Cutting Chart
## Power Hacksaw Blades

| Material | Teeth per Inch | Strokes per Minute | Feed Pressure |
|---|---|---|---|
| Aluminum Alloy | 4-6 | 150 | Light |
| Aluminum, Pure | 4-6 | 150 | Light |
| Brass Castings, Soft | 6-10 | 150 | Light |
| Brass Castings, Hard | 6-10 | 135 | Light |
| Bronze Castings | 6-10 | 135 | Medium |
| Cast Iron | 6-10 | 135 | Medium |
| Copper, Drawn | 6-10 | 135 | Medium |
| *Carbon Tool Steel | 6-10 | 90 | Medium |
| *Cold Rolled Steel | 4-6 | 135 | Heavy |
| *Drill Rod | 10 | 90 | Medium |
| *High Speed Steel | 6-10 | 90 | Medium |
| *Machinery Steel | 4-6 | 135 | Heavy |
| Manganese Bronze | 6-10 | 90 | Light |
| *Malleable Iron | 6-10 | 90 | Medium |
| *Nickel Silver | 6-10 | 60 | Heavy |
| *Nickel Steel | 6-10 | 90 | Heavy |
| Pipe, Iron | 10-14 | 135 | Medium |
| Slate | 6-10 | 90 | Medium |
| *Structural Steel | 6-10 | 135 | Medium |
| Tubing, Brass | 14 | 135 | Light |
| *Tubing, Steel | 14 | 135 | Light |

* Use cutting compounds or coolant.

# POWER HACKSAW TROUBLE CHART

| Trouble | Cause | Suggested Remedy |
|---|---|---|
| **Blade Breakage** | Blade contacting work before cutting. | Start machine with blade above work and allow automatic feed to make contact. |
| | Cutting in the same slot with a new blade previously cut by a worn blade. | Always start a new cut with a new blade, or turn the material over and saw to meet the old cut. |
| | Insufficient tension. | See tensioning chart Starrett catalog. |
| | Excessive feed when cutting thin sections. | Materially reduce the pressure. |
| | Using a worn-out blade. | Replace with new blade. |
| | Material loose in vise. | Material must be immovable, especially in gang cutting. |
| **Blade Not Cutting Straight** | Insufficient tension. | See tensioning chart Starrett catalog. |
| | Blade worn out. | Replace with new blade; an over-dull blade is both a time and money waster. |
| | Excessively hard spot in material forcing blade out of straight path. | Turn material over and start new cut. If set has become unevenly worn, replace with a new blade. |
| | Excessive pressure. | Reduce the pressure and watch the improvement in alignment. |
| | Saw frame worn in slide or out of perpendicular alignment. | Inspect adjustment of machine and adjust if necessary. |

# POWER HACKSAW TROUBLE CHART

(Continued)

| Trouble | Cause | Suggested Remedy |
|---|---|---|
| **Premature Wearing Out Of Teeth** | Excessive speed. | See suggested material cutting chart in Starrett catalog. |
| | Blades fail to lift on return stroke. | Inspect the machine for probable necessary adjustments. |
| | Excessive pressure. | See suggested material cutting chart in Starrett catalog. |
| | Teeth facing incorrectly. | Teeth should face toward the machine if a draw-cut type, away if a push-cut machine. |
| | Incorrect type blade. | See suggested material cutting chart in Starrett catalog for recommended teeth per inch. |
| | Lack of improper cutting compound. | Use reliable cutting coolant with the proper mixture for the material being cut. |
| **Blade Breaking At The Pinhole** | Excessive tension. | See tensioning chart in Starrett catalog. |
| | Blade not properly mounted. | Make sure blade is flat against the holder and pins are drawn up to end of eye before final clamping and tensioning of saw. |
| | Worn pins or improper size. | Replace with new and correct pins. |
| **Teeth Ripping Out** | Too many teeth for cutting large material. | See suggested material cutting chart in Starrett catalog for proper teeth selection for material being cut. |
| | Too few teeth for cutting thin sections. | See suggested material cutting chart in Starrett catalog for proper teeth selection for material being cut. |
| | Sawing against corner or a sharp edge. | Always have at least two teeth on the material being cut. |

## BAND SAWS

Whereas hacksaw blades are reciprocated back and forth in the cut, the blade used in band saw machines is welded to form a one-piece band which travels in one direction with a continuous cutting action. This permits efficient, high production cutting including cut-off, straight sawing and contour or profile operations.

Bands are made in a wide range of lengths, widths, thicknesses, teeth per inch and in various types for cutting metal, wood, plastics and other materials. Various types of tooth shape and tooth set are available to suit different job conditions—regular tooth, hook tooth, skip tooth, and raker set, wavy set and alternate set.

Band saw blades are also made with different types of steel and heat treatment. For metal cutting, these include regular, friction cutting, spring temper, high speed steel, special alloy and a band with a full-hard edge and special tempered back.

These bands are used on four basic types of band saw machines—standard vertical cut-off, standard vertical contour, standard horizontal cut-off and heavy duty band saw machines designed to use high speed steel bands. For more useful data on band saws see following pages.

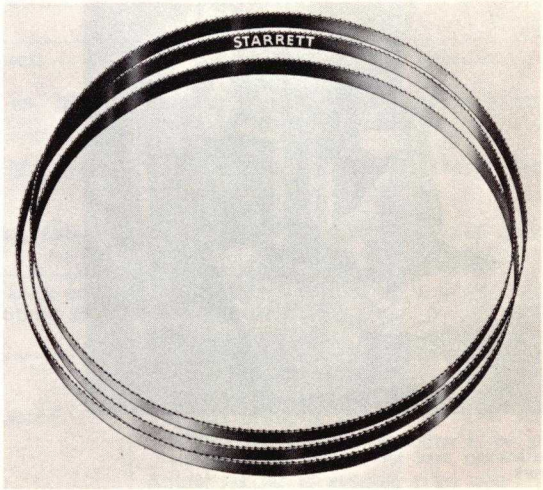



Fig. 95—Band Saws are available in either cut-to-length and welded or in coil stock for cutting metals, wood, plastics, alloys and special materials.

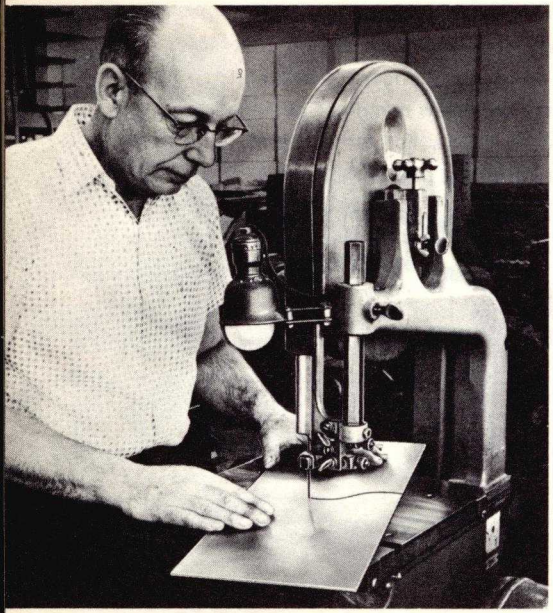


Fig. 96—A vertical contour band saw machine. Extensively used for contour cutting and die work.

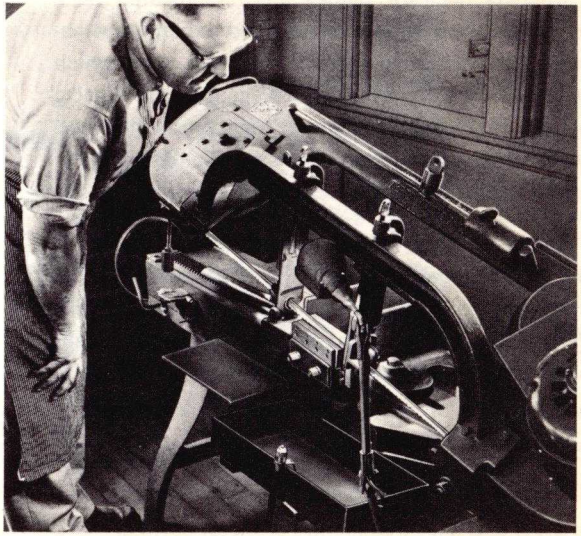


Fig. 97—A horizontal cut-off band saw machine. Used for production cut-off operations.

# BAND SAW TROUBLE CHART

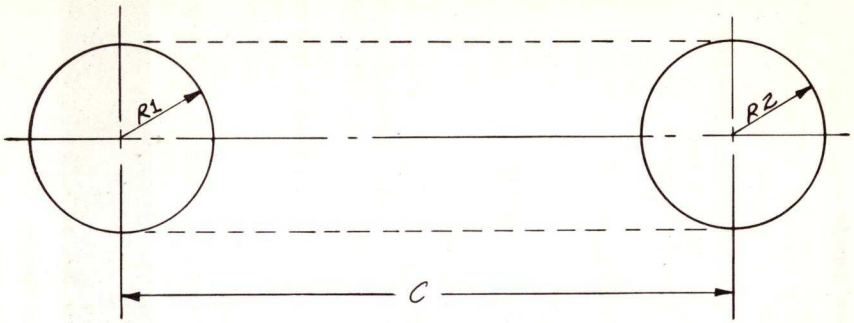
**Most Band Saw Blade Troubles Are Caused By Improper Adjustment Or Incorrect Machine Operation**

| Failure | Reason | Remedy |
|---|---|---|
| **Teeth Stripping Or Cracking** | Forcing of cut. Incorrect number of teeth, speed too slow or too fast. Starting cut on thin section or corner of material. | Use proper teeth and speed for material being cut. See chart Starrett catalog. |
| **Band Breakage Or Breakage At The Weld** | Guides not properly set. | Place guides as close as possible. |
| | Continued tension on blade when not in use. | Release tension if machine is to remain idle for any long period. |
| | Tension either too light or too heavy. | Use just enough tension to keep blade on wheels. |
| | Blade running off (not cutting straight). | Adjust guides to correct unequal wear. |
| **Burr On Back Or Grooves In Side Of Blade** | Only one of the two back edge rollers are in contact with blade. | Adjust rollers so that both share the pressure equally. |
| **Blade Running** | Forcing the cutting. | Use lighter pressure. |
| | Guides improperly spaced. | Suggest bringing guides as close as possible. |
| | Unequal wear. | Adjust guides to assume even wear. |

## Regular Hard Edge Flexible Back Metal Cutting Band Saws

| Material | Size of Material | | | Size of Material | | |
|---|---|---|---|---|---|---|
| | ½"-1" | 1"-2" | Over 2" | ½"-1" | 1"-2" | Over 2" |
| | Teeth Per Inch | | | Speed F.P.M. | | |
| STEEL S.A.E. | | | | | | |
| Carbon Steel #1010-#1095 | 14 | 10 | 6 | 175 | 150 | 125 |
| Free Machining #X1112-#X1340 | 12 | 8 | 6 | 250 | 200 | 150 |
| Nickel Chrome #2115-#3415 | 14 | 10 | 6 | 100 | 85 | 60 |
| Molybdenum #4023-#4820 | 14 | 10 | 6 | 125 | 100 | 75 |
| Chromium #5120-#52100 | 14 | 10 | 8 | 100 | 75 | 50 |
| Tungsten #7260-#71360 | 14 | 10 | 8 | 85 | 60 | 50 |
| N. E. Steels #8024-#8949 | 14 | 10 | 6 | 175 | 150 | 100 |
| Silicon Mang. #9255-#9260 | 14 | 10 | 6 | 100 | 75 | 50 |
| STEELS MISC. | | | | | | |
| Armor Plate | 14 | 12 | 6 | 100 | 75 | 50 |
| Graphic Steel | 14 | 12 | 6 | 150 | 125 | 75 |
| High Speed Steel | 14 | 10 | 8 | 100 | 75 | 50 |
| Stainless Steel | 12 | 10 | 8 | 60 | 50 | 40 |
| Angle Iron | 14 | 14 | 10 | 190 | 175 | 150 |
| Pipe | 14 | 12 | 8 | 250 | 225 | 185 |
| I Beams & Channels | 14 | 14 | 10 | 250 | 200 | 175 |
| Tubing (Thinwall) | 14 | 14 | 14 | 250 | 200 | 200 |
| Cast Steels | 14 | 12 | 8 | 150 | 75 | 50 |
| Cast Iron | 12 | 10 | 8 | 200 | 185 | 160 |
| NON-FERROUS METALS | | | | | | |
| Aluminum (All Types) | 8 | 6 | 6 | 250 | 250 | 250 |
| Brass | 8 | 8 | 8 | 250 | 250 | 250 |
| Bronze (Cast) | 10 | 8 | 8 | 185 | 125 | 50 |
| Bronze (Rolled) | 12 | 10 | 6 | 175 | 125 | 75 |
| Beryllium | 10 | 8 | 6 | 175 | 150 | 125 |
| Copper | 10 | 8 | 6 | 250 | 225 | 225 |
| Magnesium | 8 | 8 | 6 | 250 | 250 | 250 |
| Kirksite | 10 | 8 | 6 | 200 | 175 | 150 |
| Monel Metal | 10 | 8 | 6 | 100 | 75 | 50 |
| Zinc | 8 | 6 | 6 | 250 | 225 | 200 |
| NON-METALS | | | | | | |
| Bakelite | 10 | 8 | 6 | 250 | 250 | 250 |
| Carbon | 10 | 8 | 6 | 250 | 250 | 250 |
| Plastics (All Types) | 12 | 8 | 8 | 250 | 250 | 250 |
| Wood | 8 | 8 | 6 | 250 | 250 | 250 |

## To Determine the Length of a Band Saw Blade




1. Adjust wheels to correct position. Not at the outer extreme, as some take-up will be needed to tension the band. Also, not at the shortest point, as some allowance must be made for rewelding where necessary.
2. Having adjusted the wheels at about halfway in the take-up range, measure the distance from the centers of the holes between the two wheels ("C" in inches).
3. Find the radius of each wheel ("R1," "R2" in inches).
4. Use the formula.
   (R1 x 3.1416) + (R2 x 3.1416)
   + 2 x C = Band Length.

# MISCELLANEOUS MEASUREMENTS

### Measures of Length

1 mile = 1760 yards = 5280 feet.
1 yard = 3 feet = 36 inches.
1 foot = 12 inches.

The following measures of length are also used occasionally:

1 mil = 0.001 inch. 1 fathom = 2 yards = 6 feet.
1 rod = 5.5 yards = 16.5 feet. 1 hand = 4 inches.
1 span = 9 inches.

### Surveyor's Measure

1 mile = 8 furlongs = 80 chains.
1 furlong = 10 chains = 220 yards.
1 chain = 4 rods = 22 yards = 66 feet = 100 links.
1 link = 7.92 inches.

### Square Measure

1 square mile = 640 acres = 6400 square chains.
1 acre = 10 square chains = 4840 square yards = 43,560 square feet.
1 square chain = 16 square rods = 484 square yards = 4356 square feet.
1 square rod = 30.25 square yards = 272.25 square feet = 625 square links.
1 square yard = 9 square feet.
1 square foot = 144 square inches.
An acre is equal to a square, the side of which is 208.7 feet.

# THE METRIC SYSTEM

### Measures of Length

1 Millimeter (mm.) = ..... 0.03937079 inch, or about 1/25 inch
10 Millimeters = 1 Centimeter (cm.) = ..... 0.3937079 inch
10 Centimeters = 1 Decimeter (dm.) = ..... 3.937079 inch
10 Decimeters = 1 Meter (m.) = 39.37079 inches, 3.2808992 feet, or 1.09361 yards
10 Meters = 1 Decameter (Dm.) = ..... 32.808992 feet
10 Decameters = 1 Hectometer (Hm.) = ..... 19.927817 rods
10 Hectometers = 1 Kilometer (Km.) = 1093.61 yards, or 0.6213824 mile
10 Kilometers = 1 Myriaméter (Mm.) = ..... 6.213824 miles
1 inch = 2.54 cm., 1 foot = 0.3048 m., 1 yard = 0.9144 m., 1 rod = 0.5029 Dm., 1 mile = 1.6093 Km.

# DECIMAL EQUIVALENTS, SQUARES, CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCES AND AREAS OF CIRCLES, FROM 1/64 to 1/2 INCH

| Fraction | Dec. Equiv. | Square | Sq. Root | Cube | Cube | Circle* | |
|---|---|---|---|---|---|---|---|
| | | | | | | Circum. | Area |
| 1/64 | .015625 | .0002441 | .125 | .000003815 | .25 | .04909 | .000192 |
| 1/32 | .03125 | .0009766 | .176777 | .000030518 | .31498 | .09817 | .000767 |
| 3/64 | .046875 | .0021973 | .216506 | .000102997 | .36056 | .14726 | .001726 |
| 1/16 | .0625 | .0039063 | .25 | .00024414 | .39685 | .19635 | .003068 |
| 5/64 | .078125 | .0061035 | .279508 | .00047684 | .42749 | .24544 | .004794 |
| 3/32 | .09375 | .0087891 | .306186 | .00082397 | .45428 | .29452 | .006903 |
| 7/64 | .109375 | .0119629 | .330719 | .0013084 | .47823 | .34361 | .009396 |
| 1/8 | .125 | .015625 | .353553 | .0019531 | .5 | .39270 | .012272 |
| 9/64 | .140625 | .0197754 | .375 | .0027809 | .52002 | .44179 | .015532 |
| 5/32 | .15625 | .0244141 | .395285 | .0038147 | .53861 | .49087 | .019175 |
| 11/64 | .171875 | .0295410 | .414578 | .0050774 | .55600 | .53996 | .023201 |
| 3/16 | .1875 | .0351563 | .433013 | .0065918 | .57236 | .58905 | .027611 |
| 13/64 | .203125 | .0412598 | .450694 | .0083809 | .58783 | .63814 | .032405 |
| 7/32 | .21875 | .0478516 | .467707 | .010468 | .60254 | .68722 | .037583 |
| 15/64 | .234375 | .0549316 | .484123 | .012875 | .61655 | .73631 | .043143 |
| 1/4 | .25 | .0625 | .5 | .015625 | .62996 | .78540 | .049087 |
| 17/64 | .265625 | .0705566 | .515388 | .018742 | .64282 | .83449 | .055415 |
| 9/32 | .28125 | .0791016 | .530330 | .022247 | .65519 | .88357 | .062126 |
| 19/64 | .296875 | .0881348 | .544862 | .026165 | .66710 | .93266 | .069221 |
| 5/16 | .3125 | .0976562 | .559017 | .030518 | .67860 | .98175 | .076699 |
| 21/64 | .328125 | .107666 | .572822 | .035328 | .68973 | 1.03084 | .084561 |
| 11/32 | .34375 | .118164 | .586302 | .040619 | .70051 | 1.07992 | .092806 |
| 23/64 | .359375 | .129150 | .599479 | .046413 | .71097 | 1.12901 | .101434 |
| 3/8 | .375 | .140625 | .612372 | .052734 | .72112 | 1.17810 | .110445 |
| 25/64 | .390625 | .1525879 | .625 | .059605 | .73100 | 1.22718 | .119842 |
| 13/32 | .40625 | .1650391 | .637377 | .067047 | .74062 | 1.27627 | .129621 |
| 27/64 | .421875 | .1779785 | .649519 | .075085 | .75 | 1.32536 | .139784 |
| 7/16 | .4375 | .1914063 | .661438 | .083740 | .75915 | 1.37445 | .150330 |
| 29/64 | .453125 | .2053223 | .673146 | .093037 | .76808 | 1.42353 | .161260 |
| 15/32 | .46875 | .2197266 | .684653 | .102997 | .77681 | 1.47262 | .172573 |
| 31/64 | .484375 | .2346191 | .695971 | .113644 | .78535 | 1.52171 | .184269 |
| 1/2 | .5 | .25 | .707107 | .125 | .79370 | 1.57080 | .196350 |

*Fraction represents diameter.

Continued on next page

# DECIMAL EQUIVALENTS, SQUARES, CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCES AND AREAS OF CIRCLES, FROM 33/64 to 1 INCH

| Fraction | Dec. Equiv. | Square | Sq. Root | Cube | Cube Root | Circle* | |
|---|---|---|---|---|---|---|---|
| | | | | | | Circum. | Area |
| 33/64 | .515625 | .265869 | .718070 | .137089 | .80188 | 1.61988 | .208813 |
| 17/32 | .53125 | .282227 | .728869 | .149933 | .80990 | 1.66897 | .221660 |
| 35/64 | .546875 | .299072 | .739510 | .163555 | .81777 | 1.71806 | .234891 |
| 9/16 | .5625 | .316406 | .75 | .177979 | .82548 | 1.76715 | .248505 |
| 37/64 | .578125 | .334229 | .760345 | .193226 | .83306 | 1.81623 | .262502 |
| 19/32 | .59375 | .352539 | .770552 | .209320 | .84049 | 1.86532 | .276884 |
| 39/64 | .609375 | .371338 | .780625 | .226284 | .84780 | 1.91441 | .291648 |
| 5/8 | .625 | .390625 | .790569 | .244141 | .85499 | 1.96350 | .306796 |
| 41/64 | .640625 | .410400 | .800391 | .262913 | .86205 | 2.01258 | .322328 |
| 21/32 | .65625 | .430664 | .810093 | .282623 | .86901 | 2.06167 | .338243 |
| 43/64 | .671875 | .451416 | .819680 | .303295 | .87585 | 2.11076 | .354541 |
| 11/16 | .6875 | .472656 | .829156 | .324951 | .88259 | 2.15984 | .371223 |
| 45/64 | .703125 | .494385 | .838525 | .347614 | .88922 | 2.20893 | .388289 |
| 23/32 | .71875 | .516602 | .847791 | .371307 | .89576 | 2.25802 | .405737 |
| 47/64 | .734375 | .539307 | .856957 | .396053 | .90221 | 2.30711 | .423570 |
| 3/4 | .75 | .5625 | .866025 | .421875 | .90856 | 2.35619 | .441786 |
| 49/64 | .765625 | .586182 | .875 | .448795 | .91483 | 2.40528 | .460386 |
| 25/32 | .78125 | .610352 | .883883 | .476837 | .92101 | 2.45437 | .479369 |
| 51/64 | .796875 | .635010 | .892679 | .506023 | .92711 | 2.50346 | .498736 |
| 13/16 | .8125 | .660156 | .901388 | .536377 | .93313 | 2.55254 | .518486 |
| 53/64 | .828125 | .685791 | .910014 | .567921 | .93907 | 2.60163 | .538619 |
| 27/32 | .84375 | .711914 | .918559 | .600677 | .94494 | 2.65072 | .559136 |
| 55/64 | .859375 | .738525 | .927024 | .634670 | .95074 | 2.69981 | .580036 |
| 7/8 | .875 | .765625 | .935414 | .669922 | .95647 | 2.74889 | .601320 |
| 57/64 | .890625 | .793213 | .943729 | .706455 | .96213 | 2.79798 | .622988 |
| 29/32 | .90625 | .821289 | .951972 | .744293 | .96772 | 2.84707 | .645039 |
| 59/64 | .921875 | .849854 | .960143 | .783459 | .97325 | 2.89616 | .667473 |
| 15/16 | .9375 | .878906 | .968246 | .823975 | .97872 | 2.94524 | .690291 |
| 61/64 | .953125 | .908447 | .976281 | .865864 | .98412 | 2.99433 | .713493 |
| 31/32 | .96875 | .938477 | .984251 | .909149 | .98947 | 3.04342 | .737078 |
| 63/64 | .984375 | .968994 | .992157 | .953854 | .99476 | 3.09251 | .761046 |
| 1 | 1 | 1 | 1 | 1 | 1 | 3.14159 | .785398 |

*Fraction represents diameter.

# SCREW THREADS AND TAP DRILL SIZES

## N C or A. S. M. E. SPECIAL MACHINE SCREWS

| Size of Tap | Thds. per Inch | Tap Drill | Body Drill |
|---|---|---|---|
| 1 | 64 | 53 | 48 |
| 2 | 56 | 50 | 44 |
| 3 | 48 | 47 | 39 |
| 4 | 40 | 43 | 33 |
| 5 | 40 | 38 | 1/8 |
| 6 | 32 | 36 | 28 |
| 8 | 32 | 29 | 19 |
| 10 | 24 | 25 | 11 |
| 12 | 24 | 16 | 7/32 |

## N F or A. S. M. E. STANDARD MACHINE SCREWS

| Size of Tap | Thds. per Inch | Tap Drill | Body Drill |
|---|---|---|---|
| 2 | 64 | 50 | 44 |
| 3 | 56 | 45 | 39 |
| 4 | 48 | 42 | 33 |
| 5 | 44 | 37 | 1/8 |
| 6 | 40 | 33 | 28 |
| 8 | 36 | 29 | 19 |
| 10 | 32 | 21 | 11 |
| *10 | 30 | 22 | 11 |
| 12 | 28 | 14 | 7/32 |

*A.S.M.E. Only

## AMERICAN STANDARD TAPER PIPE THREADS

| Size of Tap | Thds. per Inch | Tap Drill |
|---|---|---|
| 1/8 | 27 | 11/32 |
| 1/4 | 18 | 7/16 |
| 3/8 | 18 | 19/32 |
| 1/2 | 14 | 23/32 |
| 3/4 | 14 | 15/16 |
| 1 | 11 1/2 | 1 5/32 |
| 1 1/4 | 11 1/2 | 1 1/2 |
| 1 1/2 | 11 1/2 | 1 23/32 |
| 2 | 11 1/2 | 2 3/16 |
| 2 1/2 | 8 | 2 5/8 |
| 3 | 8 | 3 1/4 |

## N F or S.A.E. STANDARD SCREWS

| Size of Tap | Thds. per Inch | Tap Drill |
|---|---|---|
| 1/4 | 28 | 3 |
| 5/16 | 24 | 1 |
| 3/8 | 24 | Q |
| 7/16 | 20 | 25/64 |
| 1/2 | 20 | 29/64 |
| 9/16 | 18 | 33/64 |
| 5/8 | 18 | 37/64 |
| 11/16 | 16 | 5/8 |
| 3/4 | 16 | 11/16 |
| 7/8 | 14 | 13/16 |
| 1 | 14 | 15/16 |
| 1 1/8 | 12 | 1 3/64 |

Tap Drills allow approx. 75% Full Thread

# NUMBER AND LETTER SIZES OF DRILLS WITH DECIMAL EQUIVALENTS

Sizes starting with No. 80 and going up to 1 inch. This table is useful for quickly determining the nearest drill size for any decimal, for root diameters, body drills, etc.

| Drill No. | Frac. | Deci. | Drill No. | Frac. | Deci. | Drill No. | Frac. | Deci. | Drill No. | Frac. | Deci. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | — | .0135 | 42 | — | .0935 | 7 | — | .201 | X | — | .397 |
| 79 | — | .0145 | — | 3/32 | .0938 | — | 13/64 | .203 | Y | — | .404 |
| — | 1/64 | .0156 | | | | 6 | — | .204 | | | |
| 78 | — | .0160 | 41 | — | .0960 | 5 | — | .206 | — | 13/32 | .406 |
| 77 | — | .0180 | 40 | — | .0980 | 4 | — | .209 | Z | — | .413 |
| | | | 39 | — | .0995 | | | | — | 27/64 | .422 |
| 76 | — | .0200 | 38 | — | .1015 | 3 | — | .213 | — | 7/16 | .438 |
| 75 | — | .0210 | 37 | — | .1040 | — | 7/32 | .219 | — | 29/64 | .453 |
| 74 | — | .0225 | | | | 2 | — | .221 | | | |
| 73 | — | .0240 | 36 | — | .1065 | 1 | — | .228 | — | 15/32 | .469 |
| 72 | — | .0250 | — | 7/64 | .1094 | A | — | .234 | — | 31/64 | .484 |
| | | | 35 | — | .1100 | | | | — | 1/2 | .500 |
| 71 | — | .0260 | 34 | — | .1110 | — | 15/64 | .234 | — | 33/64 | .516 |
| 70 | — | .0280 | 33 | — | .1130 | B | — | .238 | — | 17/32 | .531 |
| 69 | — | .0292 | | | | C | — | .242 | | | |
| 68 | — | .0310 | 32 | — | .116 | D | — | .246 | — | 35/64 | .547 |
| — | 1/32 | .0313 | 31 | — | .120 | — | 1/4 | .250 | — | 9/16 | .562 |
| | | | — | 1/8 | .125 | | | | — | 37/64 | .578 |
| 67 | — | .0320 | 30 | — | .129 | E | — | .250 | — | 19/32 | .594 |
| 66 | — | .0330 | 29 | — | .136 | F | — | .257 | — | 39/64 | .609 |
| 65 | — | .0350 | | | | G | — | .261 | | | |
| 64 | — | .0360 | — | 9/64 | .140 | — | 17/64 | .266 | — | 5/8 | .625 |
| 63 | — | .0370 | 28 | — | .141 | H | — | .266 | — | 41/64 | .641 |
| | | | 27 | — | .144 | | | | — | 21/32 | .656 |
| 62 | — | .0380 | 26 | — | .147 | I | — | .272 | — | 43/64 | .672 |
| 61 | — | .0390 | 25 | — | .150 | J | — | .277 | — | 11/16 | .688 |
| 60 | — | .0400 | | | | — | 9/32 | .281 | | | |
| 59 | — | .0410 | 24 | — | .152 | K | — | .281 | — | 45/64 | .703 |
| 58 | — | .0420 | 23 | — | .154 | L | — | .290 | — | 23/32 | .719 |
| | | | — | 5/32 | .156 | | | | — | 47/64 | .734 |
| 57 | — | .0430 | 22 | — | .157 | M | — | .295 | — | 3/4 | .750 |
| 56 | — | .0465 | 21 | — | .159 | — | 19/64 | .297 | — | 49/64 | .766 |
| — | 3/64 | .0469 | | | | N | — | .302 | | | |
| 55 | — | .0520 | | | | — | 5/16 | .313 | — | 25/32 | .781 |
| 54 | — | .0550 | 20 | — | .161 | O | — | .316 | — | 51/64 | .797 |
| | | | 19 | — | .166 | | | | — | 13/16 | .813 |
| 53 | — | .0595 | 18 | — | .170 | P | — | .323 | — | 53/64 | .828 |
| — | 1/16 | .0625 | — | 11/64 | .172 | — | 21/64 | .328 | — | 27/32 | .844 |
| 52 | — | .0635 | 17 | — | .173 | Q | — | .332 | | | |
| 51 | — | .0670 | | | | R | — | .339 | | | |
| 50 | — | .0700 | 16 | — | .177 | — | 11/32 | .344 | — | 55/64 | .859 |
| | | | 15 | — | .180 | | | | — | 7/8 | .875 |
| 49 | — | .0730 | 14 | — | .182 | S | — | .348 | — | 57/64 | .891 |
| 48 | — | .0760 | 13 | — | .185 | T | — | .358 | — | 29/32 | .906 |
| — | 5/64 | .0781 | — | 3/16 | .188 | — | 23/64 | .359 | — | 59/64 | .922 |
| 47 | — | .0785 | | | | U | — | .368 | | | |
| 46 | — | .0810 | 12 | — | .189 | — | 3/8 | .375 | — | 15/16 | .938 |
| | | | 11 | — | .191 | | | | — | 61/64 | .953 |
| 45 | — | .0820 | 10 | — | .194 | V | — | .377 | — | 31/32 | .969 |
| 44 | — | .0860 | 9 | — | .196 | W | — | .386 | — | 63/64 | .984 |
| 43 | — | .0890 | 8 | — | .199 | — | 25/64 | .391 | — | 1 | 1.000 |

# DOUBLE DEPTH OF THREADS

| Threads per In. N | V Threads D D | Am. Nat. Form D D U. S. Std. | Whitworth Standard D D | Threads per In. N | V Threads D D | Am. Nat. Form D D U. S. Std. | Whitworth Standard D D |
|---|---|---|---|---|---|---|---|
| 2 | .86650 | .64950 | .64000 | 28 | .06185 | .04639 | .04571 |
| 2¼ | .77022 | .57733 | .56888 | 30 | .05773 | .04330 | .04266 |
| 2⅜ | .72960 | .54694 | .53894 | 32 | .05412 | .04059 | .04000 |
| 2½ | .69320 | .51960 | .51200 | 34 | .05097 | .03820 | .03764 |
| 2⅝ | .66015 | .49485 | .48761 | 36 | .04811 | .03608 | .03555 |
| 2¾ | .63019 | .47236 | .46545 | 38 | .04560 | .03418 | .03368 |
| 2⅞ | .60278 | .45182 | .44521 | 40 | .04330 | .03247 | .03200 |
| 3 | .57733 | .43300 | .42666 | 42 | .04126 | .03093 | .03047 |
| 3¼ | .53323 | .39966 | .39384 | 44 | .03936 | .02952 | .02909 |
| 3½ | .49485 | .37114 | .36571 | 46 | .03767 | .02823 | .02782 |
| 4 | .43300 | .32475 | .32000 | 48 | .03608 | .02706 | .02666 |
| 4½ | .38438 | .28869 | .28444 | 50 | .03464 | .02598 | .02560 |
| 5 | .34660 | .25980 | .25600 | 52 | .03332 | .02498 | .02461 |
| 5½ | .31490 | .23618 | .23272 | 54 | .03209 | .02405 | .02370 |
| 6 | .28866 | .21650 | .21333 | 56 | .03093 | .02319 | .02285 |
| 7 | .24742 | .18557 | .18285 | 58 | .02987 | .02239 | .02206 |
| 8 | .21650 | .16237 | .16000 | 60 | .02887 | .02165 | .02133 |
| 9 | .19244 | .14433 | .14222 | 62 | .02795 | .02095 | .02064 |
| 10 | .17320 | .12990 | .12800 | 64 | .02706 | .02029 | .02000 |
| 11 | .15745 | .11809 | .11636 | 66 | .02625 | .01968 | .01939 |
| 11½ | .15069 | .11295 | .11121 | 68 | .02548 | .01910 | .01882 |
| 12 | .14433 | .10825 | .10666 | 70 | .02475 | .01855 | .01728 |
| 13 | .13323 | .09992 | .09846 | 72 | .02407 | .01804 | .01782 |
| 14 | .12357 | .09278 | .09142 | 74 | .02341 | .01752 | .01729 |
| 15 | .11555 | .08660 | .08533 | 76 | .02280 | .01714 | .01673 |
| 16 | .10825 | .08118 | .08000 | 78 | .02221 | .01665 | .01641 |
| 18 | .09622 | .07216 | .07111 | 80 | .02166 | .01623 | .01600 |
| 20 | .08660 | .06495 | .06400 | 82 | .02113 | .01584 | .01560 |
| 22 | .07872 | .05904 | .05818 | 84 | .02063 | .01546 | .01523 |
| 24 | .07216 | .05412 | .05333 | 86 | .02015 | .01510 | .01476 |
| 26 | .06661 | .04996 | .04923 | 88 | .01957 | .01476 | .01454 |
| 27 | .06418 | .04811 | .04740 | 90 | .01925 | .01443 | .01422 |

$$D\,D = \frac{1.733}{N}$$ For V Thread

$$D\,D = \frac{1.299}{N}$$ For American Nat. Form, U. S. Std.

$$D\,D = \frac{1.28}{N}$$ For Whitworth Standard

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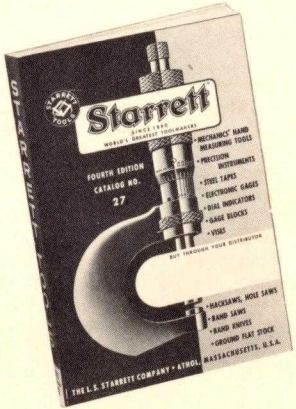


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